Limited Intakes, Low Milk and Lost Income: Investigating the Low-production Dairy Herd

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Abstract

Dairy practitioners can solve problems of low milk production in dairy herds by following a systematic approach to diagnose the underlying herd problems. Important steps in this evaluation are determining the herd signalment, objectively characterizing herd milk production and carefully evaluating herd nutritional management. Cows within the herd can then be observed for body condition score, cud chewing activity, manure characteristics, locomotion and evaluated for sickness. Important additional diagnostic information can be gleaned from herd turnover records and measures of cow comfort. Herd based testing for ketosis (BHBA and NEFA), subacute ruminal acidosis and urea nitrogen may be indicated depending on findings up to this point in the investigation. Fresh cow health problems (usually triggered by fatty liver and ketosis) or lameness (usually caused by a combination of cow environmental problems in combination with subacute ruminal acidosis) are the two most common mechanisms for low herd production. Expect to find multiple causes for low herd milk production, and put the most confidence in diagnostic conclusions that are supported by more than one measure of herd performance.

Résumé

Les vétérinaires oeuvrant dans les fermes laitières peuvent corriger des problèmes de faible production de lait par un diagnostic systématique des problèmes sous-jacents du troupeau. D'abord, il est important de bien connaître le signalement du troupeau, en observant objectivement sa production de lait et en évaluant attentivement la gestion des aliments. On peut ensuite observer les vaches sous plusieurs aspects – la condition corporelle, la rumination, les caractéristiques du fumier, la locomotion – puis, identifier leurs maladies, le cas échéant. On collectera aussi des renseignements très utiles en examinant le registre de réforme du troupeau et le confort des vaches. À ce stade, en fonction des résultats de notre investigation, il peut être indiqué de dépister, dans le troupeau, la cétose (déterminée selon le BHBA et les acides gras non estérifiés), l'acidose subaiguë du rumen et l'azote uréique. Les problèmes de santé des vaches venant de vêler (habituellement déclenchés par la toxémie de gestation et la cétose) ou la boiterie (due habituellement à la combinaison d'un environnement fautif et d'acidose subaiguë) sont les deux causes les plus fréquentes de la faible production de lait du troupeau. Attendez-vous à trouver des causes multiples à ce problème et ne basez votre diagnostic avec confiance que sur plus d'une mesure de performance du troupeau.

Introduction

Dairy practitioners are often asked to investigate dairy herds with the complaint that herd production is too low. Low herd production is almost invariably accompanied by low dry matter intakes. Many of these herds are in financial difficulty and may be in danger of losing the farm. Diagnosis of low herd production can seem daunting because of the large number of possible causes. This paper outlines an approach to investigating these herds.

Herd Signalment

A good herd investigation starts with the herd signalment. For purposes of dairy herd consulting, I have found a useful herd signalment to be the herd size, breed of cows, rolling herd average and feeding system (total mixed ration or component-fed). Clearly, determining herd signalment from the beginning creates the proper frame of reference for the remainder of the herd investigation.

Characterize the Low-production Problem

Complaints of low milk production should first be adequately characterized. Do not accept a client's complaint of low herd production without first evaluating the herd's production numbers. Few things in dairy practice are more frustrating than devoting resources to solving a perceived problem that upon further examination is actually not a problem at all. Dairy producers' perceptions of their herd problems are at times so obscured by emotion that the real problem is unspoken.

Production records vary considerably from dairy to dairy and by geographical location. Essentially every dairy sells milk by weight, so some records of milk sold should be available. If the number of cows that contributed to the milk sold each day (or pickup) is known, then simple calculations of milk production per cow, per day can be made. More information can be gained if the herd has milk meters in the parlor or has monthly milk weights from Dairy Herd Improvement (DHI) records or a similar production testing system.

Whatever record system is used, start by evaluating milk production trends over time. This is best done using a measure of milk production that includes some history and/or is corrected for expected seasonal variations in milk production. Rolling herd average and 305-day mature equivalent (ME) milk production are appropriate for this purpose. ME milk contains less history and is the most useful production monitor of these two measures.

If possible, evaluate trends in these two measures of herd production for the last two years. An example of a chart of these milk production measures from a WisGraph chart (Wisconsin DHI, AgSource Inc., Verona, WI) is presented in Figure 1. In this example, the herd has had long-standing low production (well below the owner's goal). There have been modest production improvements in the last year, although ME milk production in the second and greater lactation cows (GT1 LACT) has declined.

Milk production trends over time may also be evaluated on the basis of average daily milk yields; however, these data are difficult to interpret because they are not adjusted for normal seasonal trends. Dairies in the upper midwest region of the US typically have the highest daily milk production in late May or early June, and the lowest daily milk production in late October. Expect a difference of 4 to 8 lb/cow/day (1.8-3.6 kg) between the highest and lowest production seasons.

Daily milk yields are also not adjusted for days-in-milk, which can be an important determinant of average daily milk production. Herds with reproductive problems and extended days open have increased days-in-milk and decreased milk production due to this factor alone.

Herds that have had very recent and sharp declines in milk production may have recent changes in feeding management or may have recently introduced feed ingredients of poor quality, or may have changed diet formulation specifications. Shifts in health problems in the herd may also cause sudden drops in herd production. Recent herd expansion with subsequent overcrowding or infectious disease problems could also explain a sudden drop in herd production. Reviewing herd production records with the dairy producer and discussing herd changes that might have coincided with milk-yield changes can be extremely helpful.

Herds with chronically low milk yield are more likely to have inherent limitations in their feeding systems, feeding management, or feed ingredient quality. Long-standing herd health problems can also cause chronically low milk yield.

Evaluate Herd Nutritional Management

A complete evaluation of the herd's nutritional management is an essential component of any herd evaluation for low milk production. Since this is often the most tedious portion of the herd evaluation, it is often overlooked.

Feed ingredient evaluation

Start the nutrition management evaluation by evaluating individual feed ingredients and total mixed rations (TMR) offered on the farm. A baseline evaluation for each feed ingredient should be dry matter (DM) content, forage particle length distribution (using the Penn State Shaker box), grain particle size (using a series of grain sieves), and pH (if a fermented feed). I have found it useful to summarize this information in a standardized format (Table 1).

Problems with feed ingredient quality can be important contributors to low DM intakes and thus, low herd milk production. Of most practical significance are feeds that fermented poorly (resulting in high pH values and perhaps mold contamination), forages that are chopped too long (causing sorting of the TMR) or too short (increasing the risk for ruminal acidosis), and grain
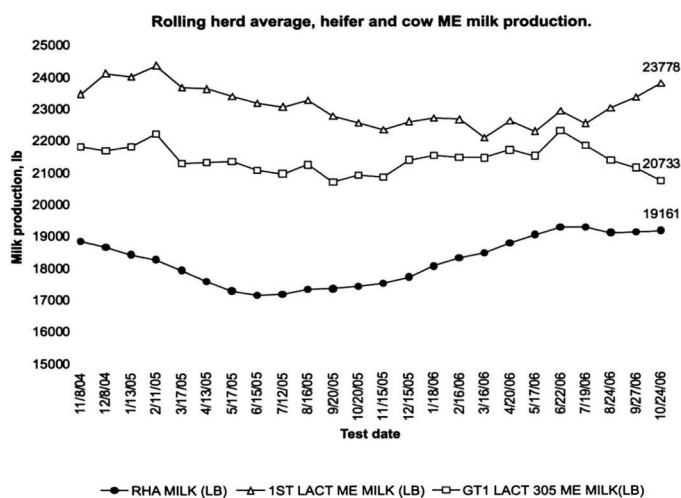
Figure 1. WisGraph plot of rolling herd average and mature equivalent (ME) milk production from a herd investigation.

Table 1. Summary of feed ingredient analyses from a herd investigation for low milk production.

Feed Ingredient	Penn State Particle Lengths			Dry Matters			pH
	% Top	% Middle	% Bottom	Actual	Assumed	Error*	
1st alfalfa silage	10	44	47	52.6	48.8	-7.2%	4.39
Goal:	15 - 25	>bottom	<middle	40 to 45		+/- 5%	4.2 - 4.8
2nd/3rd alfalfa silage	9	33	58	56.0	58.3	4.2%	4.75
Goal:	15 - 25	>bottom	<middle	45 to 55		+/- 5%	4.2 - 4.8
Corn silage	12	71	17	29.5	30.5	3.3%	3.62
Goal:	8 - 20	>>bottom	<<middle	30 to 35%		+/- 5%	3.5 - 4.0
TMR - high cows group	7	36	57	52.5	55.2	5.1%	—
Goal:	7 to 12	>bottom	<middle	40 to 50		+/- 5%	—
TMR - 1st lactation group	13	37	50	55.7	54.9	-1.5%	—
Goal:	7 to 12	>bottom	<middle	40 to 50		+/- 5%	—
TMR - late lact. group	7	37	55	52.5	52.1	-0.7%	—
Goal:	7 to 12	>bottom	<middle	40 to 50		+/- 5%	—

Grain Ingredient	Grain Sieve Particle Sizes					Dry Matters		pH
	#4	#8	#16	#30	Pan	Actual	Assumed	Error	
High moist. shelled corn	3	38	32	13	14	74.9	75.5	0.8%	5.73
Goal:	~10	~25	~30	~25	~10	75 to 78		+/- 5%	4.0 - 4.8
Dry shelled corn	1	14	32	28	26	—	—	—	—
Goal:	0	0	~30	~50	~20	—	—	—	—

*Actual dry matter values are from the day of our farm visit and determined in our laboratory (140°F [60°C] for 48 hours). The assumed DM values are those used by the producer to mix the rations on the day of our farm visit. The error is the percentage difference between the two dry matter values.

ingredients that are ground too coarsely (resulting in poor digestibility and the appearance of undigested grain particles in the manure) or ground too finely (increasing the risk for ruminal acidosis).

Feed ingredient amounts

The next step in the nutritional management evaluation is to determine the amount of each feed ingredient offered to the cows. This information usually comes from the TMR load sheets used to make each mix. Estimate the daily TMR refusal (or forage refusal if a component-fed herd) and subtract this from the total amount offered to estimate the amount of feed consumed. Then, divide feed consumed by number of cows in the group to determine average feed consumption per cow. The amount of feed actually being consumed by the cows may be considerably different than the amount specified on the load sheets.

For component-fed herds, determine the numbers of scoops, shovels, handfuls, etc. being offered to the cows, and then later carefully weigh out how much feed is in each of these measures. Do not simply take feeding amounts from the ration sheets prepared by the nutritionist. These amounts may be very different from the amounts of feed that the cows are actually consuming.

TMR mixer scale evaluation

For TMR-fed herds, the mixer scales are one of the very most important pieces of equipment on the farm, second only to the milking system. The accuracy of the mixer scales cannot be taken for granted and should also be assessed whenever there is unexplained low production. This can be done by adding 50-lb bags to the mixer with different amounts of feed already in the mixer. Alternatively, the mixer can be weighed empty and full on a platform scale.

Some mixer scales perform erratically under certain conditions, such as when the mixer is running, when feed is shifted inside in the mixer (e.g., running the mixer for a very short time so that accumulated feed does not clog feed coming in via a conveyor or auger), or when a mobile mixer is being loaded on a sloping surface. It can be extremely valuable to watch the mixer scales throughout the mixing of at least one batch of feed. Do not hesitate to have the mixer scales serviced or re-calibrated by the dealer or manufacturer. This should be done routinely at least once a year.

Estimate nutrient intake

After accurate feed intake data have been gathered, you should be able to reconstruct the ration being

consumed by the cows using a ration software program. The program used is not critical, but the accuracy of the feed ingredient amounts and analyses is. It is best to build the rations on the computer completely from scratch – this requires re-creating each mix used on the farm from its raw ingredients instead of using the composite mix analysis provided by the nutritionist.

TMR bunk sampling

A wet chemistry analysis of a carefully collected TMR bunk sample can be a useful adjunct to calculated estimates of what the cows are actually eating. Bunk sampling and testing is not a perfect representation of what the cows are eating, and several important caveats apply to interpreting these results.

It is challenging to collect a bunk sample weighing less than a pound that is truly representative of a batch of feed that may weigh 5,000 lb (2,272 kg) or more. First, the sample should be collected at or immediately after it is put in the bunk. Otherwise, cow sorting could affect the sample. Collect about 12 handfuls of feed (about a five-gallon bucket full) from the start to the end of unloading the mixer. Collect the handfuls by scooping upwards; otherwise, finer particles could be selectively lost by grabbing the sample and drawing it away from the bunk. Some suggest using pre-positioned trays in the feed bunk to collect the samples; however, the depth of feed typically placed in feed bunks often makes this impractical.

After collecting the 12 or more handfuls of TMR, place them on a flat table, gently mix, spread the feed out evenly over the top of the table and separate it into quarters. Discard two of the quarters, then re-mix the remaining feed and repeat the quartering and discarding procedure. Discard different quarters each time. Continue mixing, quartering and discarding until you have reduced the sample to about 200 grams (one pint) of feed. Then submit this entire sample to the laboratory for analysis.

TMR bunk samples must be submitted for wet chemistry analyses only – near-infrared reflectance spectroscopy (NIRS) analyses of TMR bunk samples are not as accurate because of the impossibility of creating a valid calibration set for a sample containing different feed ingredients in different proportions. I typically request wet chemistry analyses for dry matter, ether extract (crude fat), crude protein, bound protein, soluble protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, ash, calcium, phosphorus, magnesium, potassium, sodium, chloride, sulfur, copper, iron, manganese and zinc. The non-fiber carbohydrate (NFC) content of the TMR can then be calculated by subtracting the ether extract, crude protein, neutral detergent fiber and ash from 100% of the dry matter. The net energy for lactation (NEL) content of the TMR can be estimated from the ether extract, crude protein, NDF, lignin and ash values using the OARDC (Ohio) equations. Do not use NEL values for TMR mixes calculated from the ADF value alone – these NEL estimates are valid only for individual feed ingredients and cannot be applied to TMR bunk samples. Expect a TMR bunk analysis for this array of nutrients to cost about $40 to $80 and to take three to five days.

It is important that the laboratory not further sub-sample whatever TMR bunk sample you have already carefully collected and sub-sampled. TMR samples may separate considerably during shipping and handling, especially if they are relatively dry. Therefore, it is best to submit only a relatively small quantity of feed (about 200 grams or one pint of sample) and to then request that the lab dry and grind the entire sample submitted. I put this request on each bag of TMR sample that I submit for analysis. Most laboratories are glad to comply, as long as you submit only a small amount of feed.

Laboratory results for TMR bunk samples should be interpreted broadly. There are numerous causes of variation between the expected and actual TMR bunk sample analysis, including poorly representative bunk samples, undetected changes in feed ingredient analyses (especially forages), undetected inconsistencies in adding feed ingredients to the mixer wagon, and laboratory error in the wet chemistry analyses. Some of these indicate an on-farm problem that requires intervention, but others are inherent errors in TMR bunk sampling. Distinguishing among these can be difficult. I consider the expected and laboratory results to be acceptably close if they are within about ± 5% of each other (on a total nutrient basis). For instance, if the expected calcium content of a TMR was 1.00%, then any lab result between 0.95% and 1.05% would be considered acceptable.

Laboratory analysis of TMR bunk samples almost always results in slightly higher ADF and NDF values than estimated. I have come to expect about a 5 to 10% total over-estimation in ADF or NDF results from TMR bunk samples. For example, if the actual ADF content of a TMR was 19%, then the lab result would be likely be about 20.0 to 20.9%. Or if the actual NDF content of the TMR was 28%, then the lab result would likely be about 29.4 to 30.8%. The source of this bias is uncertain, but may involve the inclusion of some of the fat added to the TMR being retained in the ADF and NDF fractions during laboratory testing. The slight over-estimation of the NDF value lowers the NEL value calculated by the Ohio equation by about 2 to 3% of the total NEL value.

The greatest value in TMR bunk samples is to identify gross errors in feed analysis, mixing, or delivery. For example, omitting the salt from a custom protein mix would result in a TMR bunk sample with unexpect-

edly low sodium and chloride content. Omitting the trace mineral/vitamin premix from the ration would result in unexpectedly low copper, iron, manganese and zinc results. Feeding excessive dry matter from alfalfa haylage because the haylage became drier than the nutritionist's last analysis would result in elevated dry matter, crude protein, soluble protein, ADF and NDF values in the bunk samples. Inaccuracies in the mixer scales could result in a variety of discrepancies between the bunk sample analyses and the expected nutrient analyses.

Summarize the ration evaluations

I find it useful to summarize all the ration data – including the nutrient requirements, the ration formulated by the nutritionist, the dry matters of the feed ingredients, the expected ration and the TMR bunk sample lab analysis results – all on one sheet of paper. I tabulate this information using a spreadsheet. By clearly presenting these data, it becomes easy to identify the discrepancies and to begin tracking down their cause.

Evaluation of the Cows

It is an obvious necessity to include a general evaluation of the cows as part of any investigation of low milk production. Start by walking through the herd and evaluating general cow condition and appearance.

Body condition scoring

If cows appear to be too fat or too thin, then do formal body condition scoring of 50 or more cows in the herd. Be sure to include both far-off and close-up dry cows in the body condition scoring exercise. Then plot body condition scores by days-in-milk. An example plot is shown in Figure 2.

Once body condition scores are plotted, pay special attention to the degree of loss of body condition score in early lactation. Loss of about 1/2 unit or more of body condition score in early lactation is cause for concern.

Cud chewing activity

While evaluating cow body condition scores, you can also evaluate cud chewing activity. A minimum of 40% of cows that are not eating should be chewing their cud at any given time.

Manure evaluation

Evaluate manure characteristics while walking through the cows and doing body condition scoring. While this evaluation has limited value, it is still part of the overall evaluation. Evaluate manure consistency; very stiff manure is suggestive of a high fiber diet or perhaps lack of water availability. Very loose manure may be associated with excessive or poorly digested protein. A putrid odor to the manure may indicate severe
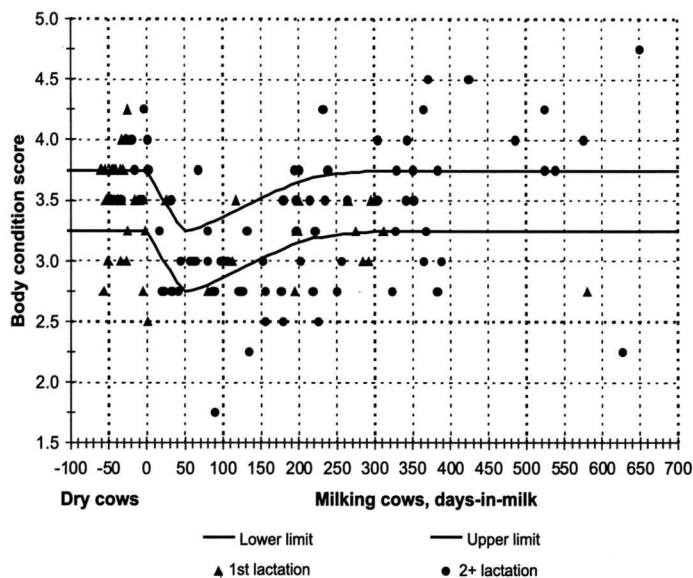
Figure 2. Example of a plot of body condition scores by days-in-milk. Based on a spreadsheet originally developed by Dr. John Fetrow.

protein over-feeding, with excessive amounts of undigested protein reaching the large intestine. Fibrin or mucin casts in the manure are suggestive of colitis, which often occurs in tandem with ruminal acidosis. Ruminal acidosis may cause looser manure or an acidic smell; however, these effects are not consistent. The presence of undigested corn particles in the manure may indicate that the grain is ground too coarsely. Dry, coarsely chopped corn silage (not kernel-processed) may unavoidably result in undigested kernels in the manure.

If you observe problems in manure consistency, you may want to gather manure samples to later wash down and screen. Collect one cup of manure from about six or more cows in the same ration or management group. Wash these samples individually over a 1/8 inch screen under warm running water. In each cow's sample there should be no more than about three pieces of undigested corn, undigested soybeans, or forage particles over about one inch in length. Inadequate processing of the corn or soybeans or poor forage digestibility (often associated with ruminal acidosis) could explain these problems.

Locomotion scoring

In herds with substantial lameness problems, I have found it very revealing to record locomotion scores of the entire herd. Because lame cows are often concentrated within certain pens (or even within certain portions of individual pens), it is very difficult to represent herd-level lameness without scoring the entire herd. This can be impractical in large herds. A subjective evaluation of lameness prevalence often has to suffice.

Examination of individual sick cows

If fresh cow health problems are part of the herd's problems, then it may be necessary to do your own examinations of sick cows that are representative of the disease problem. Depending on the disease problem, the appropriate blood samples should also be collected. Do not expect herdsmen or herd owners to accurately diagnose disease conditions. Determine the exact diagnostic criteria used to define diseases on the farm, and then examine representative animals together with the herdsman or herd owner. Inaccurate or inconclusive diagnostic information at this stage of an investigation can set the wrong course for the remainder of the herd work-up.

If the client complaint includes cow deaths, then try to have the best possible postmortem diagnosis made for all cows that die. In many situations, it is extremely valuable to identify an animal with clinical signs typical of the herd problem and then to euthanize her for a fresh postmortem evaluation. Recognize that many metabolic conditions result in no gross lesions, so do not create the expectation that a few postmortems will solve the herd's production problems. Also keep in mind that most production problems have multiple causes. Resist the urge to explain everything with a single diagnosis.

Diagnostic Dilemma – Is It Cow Health or Nutrition?

At this point in the herd investigation it is common to struggle with the cause of the low herd production. Are problems with cow health (particularly lameness or ketosis) causing the low production? Or are problems with nutritional management to blame? Or is it some of both? In most herds it is some of both. Further characterizing the herd's health problems is often needed.

Evaluate herd removals

High turnover rates are often (although not necessarily) associated with herd health problems. Turnover rate is calculated as the number of cows removed from the herd (sold or died) in the last year divided by the average number of cows in the herd for the last year. Different record systems use different calculations for turnover rates, and culling rates are usually calculated very differently from turnover rates.

A reasonable target for overall turnover rate is <30%. Cow health problems are the most common cause of high turnover rates. Early lactation turnover rates are more consistently associated with cow health problems, especially ketosis and related disorders. Early lactation turnover rates should be <4% for the first 30 days-in-milk, <2% for 31 to 60 days-in-milk and <6% for the first 60 days-in-milk. Herds with ketosis or other

fresh cow problems typically have high turnover in the first 60 days-in-milk but normal herd removals afterwards. An example distribution of herd removals from a WisGraph chart is shown in Figure 3.

Herds with lameness problems typically have high turnover rates with high numbers of herd removals throughout the lactation cycle. This is consistent with the chronic nature of lameness and its multi-factorial etiology.

Evaluation of stalls, resting surfaces and walkways

The most important cause of lameness in dairy herds is the environment in which the cow must lie down and walk. The other major factor is ruminal acidosis. An evaluation of stalls, resting surfaces and flooring surfaces has been reviewed elsewhere in detail.[2,10] Common problems observed in dairy herds include stalls that are too small, stalls with hard surfaces or surfaces that do not provide good traction for rising, and walkways that are either too abrasive or too smooth. Adequately-sized, sand-bedded free stalls are the most effective in preventing the progression of lameness in cows and allow cows to produce milk at a level closer to their genetic potential. Do not underestimate the limits that even minor problems in stall design can have on herd lameness and ultimately on herd milk production.

Additional Herd-based Testing

Basic principles of herd-based tests

If the data you have gathered to this point suggest problems with ketosis, lameness, and/or ruminal acidosis, then additional herd-based tests may be helpful to
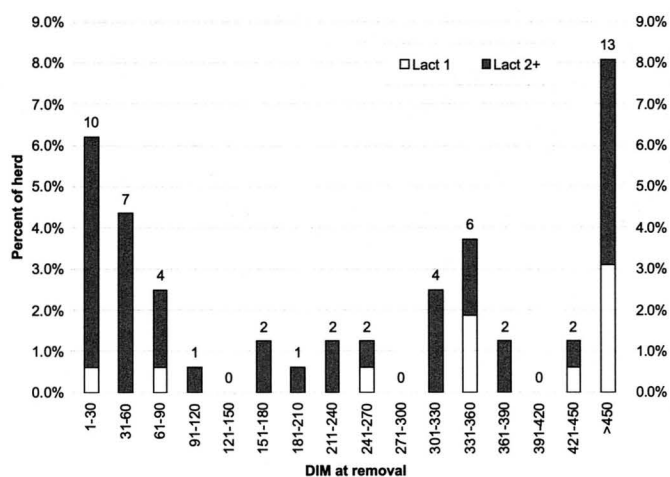
Figure 3. Example distribution of herd removals by days-in-milk. This herd's annual turnover rate was 35%; 11% of the herd was removed before 60 days-in-milk.

confirm the diagnosis.[11] Veterinarians obviously have tremendous experience in collecting, analyzing and interpreting the results of biological tests. However, veterinarians must also understand that biological test results do not stand alone in making a herd-based nutritional diagnosis. Biological test results are subject to error due to sample size, sample handling, time of collection relative to feeding and laboratory error. Thus, biological test results generally do not stand alone, but should be supported by other data from the herd investigation. For example, a finding of a high proportion of cows with low ruminal pH collected by rumenocentesis would be nicely supported by findings of low fiber diets being consumed by the cows, thin cows in the face of high energy diets, a high prevalence of laminitis-related lameness, and/or milk-fat test depression. Without supporting evidence, however, the finding of low ruminal pH alone is very suspect and is likely in error due to analytical problems in measuring pH of the ruminal fluid or random sampling error.

Interpretation of herd-based nutritional tests is very different from interpreting laboratory results from individual cows. Interpretation of individual animal test results is straightforward – just compare the animal's lab value to a "normal" range established by the laboratory that did the testing (usually a 95% confidence interval of test results from 100 or more clinically normal animals). Interpretation of group results requires a different mind-set. Normal ranges for individual animals as defined by laboratories are not necessarily pertinent. Rather, different standards for "normal" values in groups of animals must be defined by research done on groups of animals. Also, the appropriateness of the sample size must be considered, i.e., was the sample size large enough to give an adequate representation of the entire group?

The first question to ask when interpreting biological test results is whether we want to interpret the mean test result, or the proportion of animals above or below a certain cut-point. The biology of the disease we are trying to diagnose determines which interpretive approach is the most appropriate. Ruminal pH, β-hydroxy-butyric acid (BHBA) and non-esterified fatty acid (NEFA) are tests for diseases in which animals are affected only when they are above or below a certain biological threshold (cut-point). For example, ruminal pH ≤5.5 puts cows at risk for subacute ruminal acidosis (SARA) with subsequent rumenitis and other complications.[5] Ruminal pH values above 5.5 are considered "normal" in that they do not put animals at risk for SARA. So, we are not interested in interpreting mean ruminal pH values, but rather in interpreting the proportion of animals with ruminal pH below the 5.5 cut-point.

The BHBA and NEFA test results are likewise interpreted on a proportional basis. The BHBA test is used to detect ketosis. Research has identified 14.4 mg/dl (1400 μmoles/l) as the cut-point for significant ketosis.[3] So, we evaluate this test on the basis of the proportion of animals with BHBA values above 14.4 mg/dl. This herd-based cut-point is considerably higher than the upper end of the laboratory normal reference range for individual cows. The NEFA test is an indicator of negative energy balance (with subsequent risk for fatty liver, ketosis, displaced abomasum, retained placenta and infertility) in pre-fresh cows. Threshold values of above 0.400 mEq/l in cows between two and 14 days from calving (or above 0.325 mEq/l if more than 14 days from calving) have been established as the appropriate cut-points. Again, we are not interested in the mean NEFA value from a group of pre-fresh cows, but rather in the proportion of cows above the cut-point.

Besides defining the appropriate cut-points for these tests, it is also necessary to determine the alarm level for the proportion of animals above (or below) the described cut-point. In any dairy herd, we expect a few individual animals to be above or below the cut-points. The alarm level is established from research results and/or clinical experience with these tests in herd settings. Suggested cut-points and alarm levels for ruminal pH, BHBA and NEFA test results are listed in Table 2.

Urea nitrogen (UN), measured in milk or blood, can be useful to confirm ration problems that result in an imbalance between ruminally available protein and carbohydrates. For this test, an evaluation of the mean value is most appropriate. There is no single biological threshold for UN. Instead, there is an "optimal" range of about 10 to 14 mg/dl. Note that the normal range for UN in groups of cows is considerably narrower than the normal reference range for individual cows. Either exceeding or falling short of this optimal range represents a nutritional problem that could result in low milk production. So, the mean test result from a group of animals is the most appropriate method of interpretation.

It is important to sample enough cows in each group of eligible animals in order to have reasonable confidence that the results (either a proportion or a mean) truly represent the entire population of eligible animals on that farm. We do not, however, need to sample as many animals as a researcher would sample in order to achieve a 95% confidence ($P < .05$) in the results. Rather, a 75% confidence is acceptable under most herd testing conditions. Certainly larger sample sizes are desirable and will increase your confidence in the result; however, practicality and cost constraints may dictate that you choose an "optimal" sample size that is smaller.

When solving herd nutritional problems, there is never the option to make "no decision." Leaving things the way they are is just as active a decision as implementing a nutritional change. Thus, lower confidences

Table 2. Cut-points and alarm levels for proportional herd-based nutritional tests.

Test	Cut-point	Alarm level Proportion	Associated risk
Ruminal pH	≤ 5.5	> 25%	Subacute ruminal acidosis
BHBA	> 14.4 mg/dl	> ~10%	Ketosis
NEFA	> 0.400 mEq/l if -2 to -14 days pre-calving	> ~10%	Prepartum negative energy balance, fatty liver

due to smaller sample sizes are both acceptable and reasonable.

As a general rule, a minimum of about 12 eligible cows should be sampled for tests with proportional outcomes (ruminal pH, BHBA and NEFA) and a minimum of about eight total animals should be sampled for UN, which is interpreted as a mean. An alternative to sampling individual cows for UN is to test the bulk-tank milk (or a pen sample of milk) for MUN. Larger sample sizes are always required when evaluating tests with proportional outcomes compared to mean outcomes.

Sample sizes larger than about 12 animals are suggested when the results of a proportional outcome are very close to the cut-point. For example, if 2/12 (16.7%) of cows tested for ruminal pH had pH <5.5, then it would be reasonable to test additional cows. The upper end of a confidence interval of this value would be above the cut-point of 25%. In contrast, if 5/12 (41.7%) of the cows tested had ruminal pH <5.5, then additional testing would not be warranted because the lower end of a reasonable confidence interval of the value would still be above the cut-point.

Cows to be sampled for these tests need to come from the appropriate "eligible" or "at-risk" group. It is of no clinical value to test cows for a condition for which they have no risk due to their current stage of lactation. Appropriate eligible groups for herd-based nutritional tests are listed in Table 3.

The size of the eligible group for testing has some, but limited influence on the appropriate sample size. In larger herds, there is little statistical value in testing more animals. The same sample size will yield almost the exact same information about the group average, even when the group is large. In smaller herds, it may be possible to test the entire eligible group and still not have an adequate sample size. For example, only the pre-fresh cows (from three weeks prior to expected calving up to calving time) are eligible for NEFA testing. If there are only four cows in the group, then all four should be tested. However, a sample size of four cows is too small to be conclusive. So, additional cows should be tested as they more into the eligible group, and the group results interpreted only after about eight or more test results have been accumulated. If

Table 3. Appropriate groups of cows eligible for different herd-based nutritional tests.

Test	Eligible Group
Ruminal pH	Lactating cows, about 5 to 150 days-in-milk
BHBA	Lactating cows, about 5 to 50 days-in-milk
NEFA	Pre-fresh cows, ideally 2 to 14 days from actual calving
UN	Lactating cows at any stage of lactation; may evaluate sub-groups

cows are repeatedly tested for NEFA as they approach calving, only the last test result before actual calving for that cow should be used when interpreting the test results (i.e., do not use multiple test results from the same cow to achieve your sample size goal).

Ruminal pH testing for subacute ruminal acidosis

Ruminal pH is the definitive test for ruminal acidosis. Subacute ruminal acidosis (SARA) is the most common form of ruminal acidosis encountered in dairy herds (acute ruminal acidosis is rare). SARA interacts with problems in stall design and surface cushion to cause lameness problems in herds. Herds with a high prevalence commonly exhibit low milk yields, poor reproductive performance and high turnover rates (spreading across all days-in-milk).

Although ruminal pH is the best test we currently have for diagnosing SARA, it is a very limited test. Ruminal pH may vary from day to day and time of day within a herd. Thus, single samplings of a group of cows are vulnerable to error.

Another potential source of error in ruminal pH measurements is the accuracy and correct calibration of the pH meter. Use a high-quality pH meter for this purpose – pH paper is not accurate enough and is influenced by the green color of the ruminal fluid. We use the Cardy Twin pH Meter (Spectrum Technologies, 23839 W. Andrew Rd., Plainfield, IL 60544, 800-248-8873 or http://www.specmeters.com). This meter is made for field use, requires only a small volume of ruminal fluid, has an automatic calibration routine, and automatically

compensates for the temperature of the sample. However, this pH meter (and probably any others on the market) does not work well when operated at cold temperatures. Therefore, in cold weather I bring all the ruminal fluid samples (in capped syringes with the air excluded) into a warm parlor or office to run the pH determinations. Also, pH electrodes get dry while they are not being used, and it can take a while to get them soaked and stable. It is best to calibrate the meter twice before actually running any samples. After the last calibration, put the pH 7 and pH 4 buffers back on to see how close they read to their actual pH. The best approach to setting up this meter is to put some pH 7 buffer on the meter before starting to collect the ruminal fluid. Then calibrate the meter after the samples are collected. This gives the electrode plenty of time to soak, and it should calibrate noticeably better after this soaking period.

A practical sample size for most herds is 12 animals per diet. If three or more of the 12 cows tested have a ruminal pH ≤5.5, then the group is considered to be at high risk for SARA and the diet should be modified to reduce the risk for SARA. This testing scheme works very well for herds with high (>30%) or low (<15%) prevalences of cows with low ruminal pH. Example guidelines for interpreting ruminal pH test results are listed in Table 4.

The intended purpose of the rumenocentesis test is to identify herds with high prevalences of cows with low ruminal pH. These herds require immediate dietary corrections. Herds with intermediate prevalences (16.7 to 33.3%) of low ruminal pH may require a greater sample size to be classified correctly, or may require that other diagnostic indicators of SARA be more carefully considered. Immediate dietary intervention is not critical in herds with intermediate prevalences, so it is not unreasonable to take additional time to gather more information.

The effect of time relative to feeding on ruminal pH is great. The purpose of this test is to identify cows with low ruminal pH, so sampling should be done around the time of the expected lowest point (nadir). In component-fed herds, the nadir in ruminal pH occurs about two to four hours post-feeding. In TMR-fed herds, the nadir in ruminal pH occurs about six to 12 hours post-feeding.[8]

Key causes for SARA that we have observed in the field include rapid introduction of concentrates after calving, short forage particle length, excessive sorting of the TMR at the bunk, inaccurate estimates of forage dry matter, very rapidly fermentable carbohydrate sources, unexpectedly high NDF digestibility (due to feed processing or moisture content) and inadequate dietary buffering.[9]

BHBA testing for ketosis

Ketosis can be an important cause of low milk production in dairy herds. Although it occurs almost exclusively in early lactation (less than 50 days-in-milk), ketosis causes reduced dry matter intake and reduced peak milk yield. This sets a lowered milk production curve for the entire lactation. Ketosis has become increasingly prevalent in dairy herds in the upper midwestern US. This may be explained by our dairy industry changing from housing cows individually in small tie-stall or stanchion herds to housing cows in groups in larger herds with free stalls and parlors. Overcrowding group pens and the stress of pen moves just before and after calving appear to be important risk factors for ketosis in free stall herds.

The "gold standard" test for ketosis is blood BHBA. This ketone body is more stable in blood than acetone or acetoacetate. Canadian research[3] has defined a cut-point of 1400 μmoles/l (14.4 mg/dl) BHBA for ketosis. Above this cut-point, cows are at increased risk for displaced abomasum, clinical ketosis and decreased milk production. Clinical ketosis generally involves much higher levels of BHBA (26 mg/dl or more).

The alarm level for the proportion of cows above the cut-point of 14.4 mg/dl BHBA has not been well defined. Studies show an average prevalence of about 15% ketosis in early lactation cows. My clinical impression is that we should tolerate no more than about 10% ketosis in early lactation cows. Most herds I test have a 0 to 8% prevalence of ketosis. An example interpretation guide for BHBA testing is presented in Table 5.

The BHBA test can be performed on serum samples, and there are no special sample handling requirements. Serum BHBA concentrations typically increase after feeding.[4] Consistent sampling at four to five hours after the start of feeding has been suggested in order to capture peak BHBA concentrations. The post-feeding peak in serum BHBA concentrations is due to ruminal production of butyric acid. Excess amounts of butyric acid (either from ruminal production or from silage) are easily converted to BHBA in the wall of the rumen.

Table 4. Interpretation of ruminal pH test results (group size = 100; sample size = 12; confidence interval = 75%; alarm level = 25%).

Outcome	Percentage	Interpretation
0/12	0%	negative
1/12	8.3%	negative
2/12	16.7%	borderline
3/12	25.0%	borderline
4/12	33.3%	borderline
5/12	41.7%	positive
6/12	50.0%	positive

Table 5. Interpretation of BHBA test results for ketosis (group size = 50; sample size = 12; confidence interval = 75%; alarm level = 10%).

Outcome	Percentage	Interpretation
0/12	0%	negative
1/12	8.3%	borderline
2/12	16.7%	borderline
3/12	25.0%	positive
4/12	33.3%	positive
5/12	41.7%	positive
6/12	50.0%	positive

An evaluation of early lactation cows for ketosis requires testing most or all of the eligible cows in small to medium-sized herds. In larger herds, a suitable sample size may be obtained on a single herd visit.

Clinical signs of ketosis are non-specific and subtle. They include depressed dry matter intake, impaired milk production, increased risk for displaced abomasum, and occasionally nervous signs are seen. Criteria for defining ketosis and intensity of detection vary widely among herds. Many dairy herds are completely unaware that they have a ketosis problem. It can be particularly difficult to diagnose ketosis in free-stall herds because individual cow feed intakes are not typically monitored. Not surprisingly, during my herd-level evaluations for ketosis I have discovered many individual cows with extremely high blood BHBA concentrations (above 30 mg/dl) that should have been identified as being ketotic. In such cases, the herd has not only a ketosis problem, but also a problem of inadequate disease recognition in early lactation cows. The best approach I have found for detecting ketotic cows is to routinely lock up the post-fresh cows to fresh feed after the first milking of the day. Adding a small amount of baled hay on top of the TMR in the bunk encourages a better lock-up after milking. After the cows have been locked up for a few minutes, walk down the bunk in front of the cows and observe feed consumption and evaluate each cow's appearance. Cows with low feed intake, depressed appearance, or low milk production can then be evaluated for urinary or blood ketones. Early identification of these cows allows for individual cow treatment with glucose precursors, plus alerts the producer to underlying nutritional problems. My clinical experience suggests that many cases of displaced abomasum can be prevented by prompt detection and treatment of ketosis.

Common causes of ketosis include high protein / low energy diets in early lactation, pre-existing fatty liver due to negative energy balance late in the pre-fresh period and ingestion of excessive butyric acid in very wet silages due to clostridial fermentation. Problems with nutrient balance in early lactation tend to cause elevated BHBA concentrations that are evenly distributed by days-in-milk in early lactation. Ketosis caused by pre-existing fatty liver late in the pre-fresh period tends to cause elevated BHBA concentrations in the first five to 15 days-in-milk. These cows often have other manifestations of fatty liver, including immune suppression and lack of response to ketosis treatment.

NEFA testing for pre-partum negative energy balance

The NEFA test is used to evaluate the presence of negative energy balance prior to calving. Cows should stay in positive energy balance up until the last 24 to 48 hours prior to calving. Negative energy balance is expected in milking cows, so the NEFA test is harder to interpret and is not typically evaluated after calving. Elevated NEFA concentrations in pre-fresh cows are associated with high risk for fatty liver, ketosis and other periparturient diseases.[7] Elevated NEFA concentrations in pre-fresh cows are also associated with increased risk for displaced abomasum after calving.[1]

Based on this physiological understanding of NEFA, it is best positioned as a secondary test in a herd already known to have a high incidence of ketosis. The NEFA testing helps determine whether the postpartum ketosis is due to pre-calving negative energy balance and fatty liver. There is little value in conducting NEFA testing in herds with a low incidence of ketosis, since ketosis is the main problem associated with high NEFA prior to calving.

Michigan workers have described a NEFA cut-point of 0.400 mEq/l in pre-fresh cows from which the sample was collected between two and 14 days before actual calving. NEFA concentrations normally rise in the last 48 hours prior to calving, so results from cows that calve this soon after the sample was collected are difficult to interpret and should either be discarded or interpreted with caution. If these samples are submitted, it would be reasonable to also test them for BHBA. Dry cows are generally at very low risk for ketosis; however, their risk may rise considerably in the final 48 hours prior to calving.

The alarm level for the proportion of cows with elevated NEFA concentrations within a group has not been precisely defined. My experience with this test, often in herds with serious pre-fresh diet problems, is that no more than 10% of the cows tested should have elevated NEFA concentrations. Thus, the same interpretation strategy is used as for interpreting BHBA results (Table 5).

In small dairy herds, the number of pre-fresh cows eligible for NEFA testing is small, so all eligible cows will need to be tested. Samples may need to be frozen and submitted as a group when about 12 or more have been accumulated. It makes sense to store the frozen plasma samples over time, and to wait until all calving

dates for the cows are known and an adequate sample size has been accumulated before submitting the samples to the lab.

In large dairy herds, the pre-fresh group may be sub-sampled for NEFA screening. In this case, select the cows that appear to be closest to calving, but avoid cows in which calving appears to be imminent. I have found it extremely useful in some investigations to collect some plasma samples from cows in the maternity pen as well as the pre-fresh pen, even if the maternity pen cows appear to be very close to calving. Many of these cows will not calve for several more days, which indicates both a management error and puts them at risk for elevated NEFA concentrations. A good pre-fresh nutritional management program can be ruined if a cow is forced to spend several days in a maternity pen without adequate access to feed, water and resting space.

Concentrations of NEFA reach their nadir about four to five hours post-feeding[4] and peak just prior to the next feeding. The best approach, therefore, is to sample just prior to or within 30 minutes of the main (usually first) feeding of the day in order to capture the peak value. The difference between peak and nadir values is probably influenced by the availability of feed throughout the day and the relative size of meals consumed by the cows.

If a high proportion of elevated NEFA concentrations are detected, then attention should be focused on increasing total energy intake in the pre-fresh group. This may require increasing the energy density of the pre-fresh diet, increasing pre-fresh dietary NFC content, improving diet palatability, increasing bunk space, increasing feeding frequency and/or increasing daily feed refusals.

Urea nitrogen testing

Blood UN (BUN) or milk UN (MUN) are indirect measures of protein and energy nutrition in lactating cows. Measures of UN can help confirm problems identified in the ration evaluation. High UN may be caused by either high dietary crude protein (especially soluble protein) and/or low dietary NFC. High UN are a risk factor for infertility and body condition score loss due to the energy cost of detoxifying excessive ruminal ammonia into urea by the liver.

The effect of time relative to feeding on UN concentrations is great,[6] particularly if the protein is fed as a separate component of the diet two or three times a day (Figure 4). Lack of control of the time of UN sampling relative to feeding has greatly hindered the effectiveness of this test in the past. Sampling at about three hours after a major protein feeding should assist in determining peak daily UN concentrations. Consistent time of sampling relative to feeding is necessary when monitoring a herd over time.

Milk UN concentrations are closely related to BUN concentrations (Figure 4). Therefore, either BUN or MUN samples are acceptable for evaluating herd UN. Bulk-tank MUN is particularly attractive because it provides a mean value for a large group of lactating cows with a single test, without concern of getting an adequate sample size. Wet chemistry procedures for MUN are preferred over NIRS tests because they are more accurate. Because bulk-tank MUN testing is inexpensive and accurate (as long as a wet chemistry analysis is used), and because UN is evaluated on a basis of the group mean, bulk-tank MUN screening is a reasonable procedure to conduct on a routine basis. Individual cows (or milking strings) could then be evaluated for UN if the bulk-tank MUN value falls outside the optimum range.

Conclusions

Causes of low milk production can be identified in most dairy herds. Most herds have multiple reasons for the low production, and comprehensive herd evaluation is the best approach. The most robust conclusions about the herd come when a variety of different measures, all with different sources of potential error, lead to the same conclusion.

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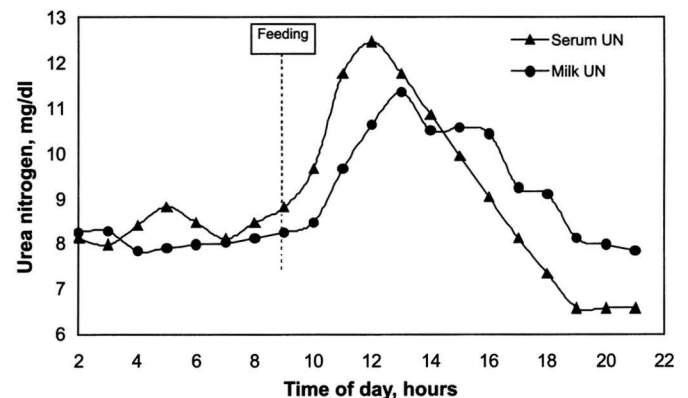
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