PEER REVIEWED

Clinical Trial to Determine the Productivity Impact of Milk Urea Nitrogen Reports

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Abstract

A clinical trial was conducted to determine the perceived and actual utility of milk urea nitrogen (MUN) notification and interpretation as a tool for monitoring protein and energy imbalances in dairy cows. Based on MUN results during the summer of 2001, 50 farms with high MUN values and 30 with low values were randomly allocated to become either intervention or control farms. From January to November 2002 (the trial period), intervention included monthly notification of individual cow MUN results, interpretation of abnormal average MUN values in subgroups of cows based on parity and days-in-milk, and suggestion of possible nutritional reasons for the abnormal MUNs. Intervention farms responded to a survey regarding report utilization, subsequent feed changes and perceptions of MUN testing. Control farms received the individual cow MUN results, but no additional interpretation. No significant differences in average MUN or standardized milk production between intervention and control farms were seen during the last three months of the trial (the outcome period). However, in herds making a feed change in response to MUN notification and interpretation (71% of intervention herds), milk production increased 2.4 lb (1.1 kg)/cow per day in the month after the feed change when compared to randomly selected herds not making a feed change during the same time period. Most dairy producers receiving the MUN notification and interpretation reports felt they knew how to use MUN reports after the trial, and felt that MUN testing was at least somewhat useful as a nutritional tool.

Résumé

Un essai clinique a été mené afin de déterminer l'utilité perçue et réelle de rapporter et d'interpréter les valeurs d'azote uréique du lait afin de surveiller les changements dans le bilan en énergie et en protéines des vaches laitières. Sur la base des valeurs d'azote uréique du lait établies durant l'été de 2001, 50 fermes avec des valeurs élevées d'azote uréique du lait et 30 fermes avec des valeurs basses ont été allouées aléatoirement soit à un groupe recevant une intervention ou soit à un groupe témoin. De janvier à novembre 2002 (la période de l'essai), le groupe avec intervention recevait mensuellement les valeurs individuelles d'azote uréique du lait avec interprétation des moyennes anormales dans des sous-groupes de vaches selon la parité et le nombre de jours en lait et aussi des suggestions sur les raisons nutritionnelles possibles causant des valeurs anormales d'azote uréique du lait. Les fermes dans le groupe d'intervention remplissaient un questionnaire sur l'utilisation des rapports, les changements subséquents dans l'alimentation et la perception de la surveillance de l'azote uréique du lait. Les fermes témoins recevaient les rapports individuels d'azote uréique du lait mais sans interprétation. Il n'y avait pas de différence significative entre les fermes du groupe avec intervention et les fermes témoins au niveau de la valeur moyenne de l'azote uréique du lait ou de la production de lait corrigée lors des trois derniers mois de l'essai (la période de test). Toutefois, dans les fermes qui ont apporté un changement à l'alimentation suite à l'interprétation des résultats d'azote uréique du lait (71% des fermes avec intervention), la production s'est accrue de 2.4 lb (1.1 kg) par vache par jour dans le mois suivant le changement alimentaire par rapport à celle rapportée dans des troupeaux choisis aléatoirement parmi l'ensemble n'ayant pas apporté de changement dans l'alimentation dans la même période. La plupart des producteurs laitiers qui recevaient les rapports sur l'azote uréique du lait avec interprétation croyaient qu'ils

savaient comment utiliser ces derniers après l'essai et que la surveillance de l'azote uréique du lait était à tout le moins assez utile comme outil de régie de la nutrition.

Introduction

It is difficult for dairy producers to provide sufficient but not excess protein with suitable amino acid (AA) profiles, and to balance them with energy sources for efficient rumen fermentation.[6,9] High producing dairy cows require an appropriate amount of high quality protein with the desired amount of essential AA to be presented to the lower digestive tract to sustain lactational and metabolic function.[25,30] Ruminal microorganisms are a good source of high quality protein, but they do not supply sufficient amounts of metabolizable protein to support maintenance and high levels of milk production.[13,14,16,20,23] Undegradable intake protein (UIP) can substantially increase the amount of protein for digestion and the flow of AA to the small intestine for absorption.[15,34,35]

Balancing these many factors when formulating a dairy ration can be even more challenging with potentially wide variation in quality of stored feeds and pastures temporally (from week to week) and spatially (from field to field). Dairy producers could benefit from a nutritional monitoring tool that would help them to detect inappropriate feeding of protein and energy. Many dairy herd improvement (DHI) corporations in North America routinely measure and report milk urea nitrogen (MUN) values to their customers at low cost. This service is based on the assumption that MUNs will identify imbalances in protein and energy feeding, and feed changes to address these imbalances will pay for the cost of the MUN service in commercial dairy herds.[22,29]

Previous experimental studies have shown that blood urea nitrogen (BUN) increases as dietary crude protein (CP) increases,[5,21,36] whereas other studies have shown strong correlation between MUN and BUN.[8,21,24,31] MUN levels can be low if the ration is deficient in protein, or if there is an excess of fermentable energy from carbohydrates relative to protein availability in the rumen.[11,12,32] However, studies in commercial dairy herds[18,27] have shown that the relationship between MUN and dietary components was weaker than reported from studies carried out under controlled experimental settings.[8,32] Furthermore, there is little scientific evidence to support anecdotal opinion that the use of MUN as a nutritional monitoring tool is beneficial in commercial dairy herds.

For MUN test results to be of value to a dairy producer, a number of steps are required. First, a dairy producer paying for MUN information needs to decide whether MUN values for certain groups of cattle in the herd are too high or low. If MUN values are out of the normal range (10-14 mg/dL),[17] the farmer, perhaps with the assistance of a nutrition advisor and/or veterinarian, needs to determine the cause of the abnormal MUN values. He or she would then make changes to the ration, hopefully resulting in MUN values in the normal range and improved cattle productivity. To our knowledge, there is no report of a formal evaluation of benefits of using MUN testing for monitoring and adjusting nutritional imbalances in protein and energy in commercial dairy herds.

Therefore, the objectives of this randomized controlled clinical trial were: 1) to determine the impacts on a) MUN and b) milk production associated with MUN results notification and interpretation reports, regardless of any specific changes in management; 2) to determine the impacts on a) MUN and b) milk production associated with nutritional changes that occurred specifically in response to MUN results notification and interpretation reports; and 3) to assess the perceived utility of MUN testing by producers participating in the clinical trial. This study was part of a larger research program investigating the variability, factors, impacts and utility of MUN testing on dairy farms in Atlantic Canada. None of the participating farmers had experience with MUN testing prior to the project because routine testing of monthly milk samples for MUN was unavailable to them prior to the program.

Materials and Methods

Herd Selection and Intervention

The target population for the study included all dairy farms in the Canadian province of Prince Edward Island (PEI) that received monthly milk testing by the Atlantic Dairy Livestock Improvement Corporation (ADLIC). This provided 198 herds containing 13,363 lactating cows for possible inclusion in the study, representing approximately 70% of all dairy farms in the province.

To demonstrate the effect of notification and interpretation of MUN abnormalities, herds with a high probability of experiencing abnormal MUN tests during the clinical trial were required. Therefore, an initial herd categorization was conducted, based on an initial "group categorization period", the summer of 2001 (June-August), during which all milking cows in the target population were tested monthly for MUN levels as part of an on-going research project on MUN. This period was selected because previous research involving dairy cattle in this region demonstrated significantly higher MUN concentrations during summer than other times of the year,[4] likely due to high levels of soluble protein in fresh grass on pasture.[37] All study herds were on pasture during the summers of 2001 and 2002. MUN concentrations were measured using infrared testing with a Fossomatic 4000 Milkoscan Analyzer at the PEI Milk Quality Laboratory in Charlottetown, PEI. MUN test results from this instrument have been validated by blindly comparing 30 samples every three months during the trial period with an enzymatic test (CL10), producing excellent precision and validity (n = 161), as reported elsewhere.[2] MUN results during this group categorization period were used to calculate a herd average MUN (HA-MUN) concentration for each month. The monthly HA-MUNs were averaged to categorize each farm into historically high (> 14 mg/dL), normal (10 to 14 mg/dL) or low (< 10 mg/dL) MUN groups.

From the historical high MUN group, herds were randomly allocated and recruited by mail until 25 herds agreed to participate as intervention herds. This herd sample size represented half of the total herds in the historically high MUN group, leaving 25 herds who agreed to participate as control herds from the high MUN group.

Although high MUN values were of primary concern to dairy producers due to implications for feed costs and reproductive efficiency,[10,26,33] low MUN concentrations also represented imbalanced feeding. Because altering management practices to increase low MUN offered opportunities for improved productivity, this group was also included in the trial. However, there were only eight herds in the historically low MUN group during the group allocation period. Therefore, the definition of the historically low MUN group was relaxed to include herds with average HA-MUN values of 11.5 or lower during the group allocation period. This was considered justified, as MUN values have been shown to be 1.5 mg/dL higher in summer months than at other times during the year in PEI.[1] With this relaxed definition, 30 herds fell into the historically low MUN group, and therefore 15 herds were randomly selected and agreed to participate as intervention herds in the study, leaving 15 historically low MUN herds who agreed to participate as control herds.

Intervention Definition and Data Collection

The clinical trial was conducted from January to November 2002 (the "trial period"), capturing the winter stabling period of January to May, and the subsequent spring, summer and fall pasture seasons. For both the intervention and control herds, MUN results were sent monthly to dairy producers within the normal package of herd test results from ADLIC. In addition, for intervention herds, nutritional advisors (usually a feed company representative) also received a copy of the individual cow MUN results. The nutritional advisors and dairy producers also received MUN summary sheets and an interpretation report of average MUN concentrations for the farm, by stage of lactation and parity subgroups of cows. Stage of lactation categories included early (0 to 100 days), mid- (101 to 200 days) and late (> 200 days) lactation, and parity categories included first, second and third-plus lactation. The interpretation reports indicated which subgroups of cows had low or high average MUN concentrations that month, and a list of likely feed-related causes for those abnormal averages. The intention of this intervention was to instigate a review of the ration and feeding management, leading to subsequent feeding changes if deemed appropriate and possible for the farmer.

Questionnaires were developed and sent to intervention farms twice during the 11-month trial period to obtain information about: 1) their response to the MUN data notifications and interpretations; 2) their knowledge of how to use MUN data; and 3) their perceptions on the utility of MUN data. For the producers who had failed to return the questionnaire in a timely manner, phone calls were made to encourage them to complete and return the questionnaires and, in a few cases (n = 7), to complete the questionnaire over the phone.

During the 11-month trial period, individual cow milk samples from the monthly ADLIC milk test were collected and tested for MUN and milk components (fat, protein and somatic cell count - SCC). Milk test data, production levels, days-in-milk and parity of each cow were obtained electronically from the ADLIC database for the test dates just before, during and just after the trial period.

A standardized measure of milk production (standard milk, or S-milk) was computed by adjusting milk production for each herd for: 1) breed; 2) parity; 3) stage of lactation; and 4) milk component concentrations.[28]

Statistical Methods

To address objectives 1a and 1b, mean HA-MUN and mean S-milk were calculated for the last three months of the trial (September, October and November 2002 – the "outcome period"). Due to monthly variability in MUN concentrations and milk production reported in PEI in the past,[1] a mean HA-MUN over three months was deemed to be more representative of a farm than a single HA-MUN. Mean HA-MUN and S-milk during the outcome period served as the outcome variable for linear regression analyses, and predictors to be investigated included intervention herd (yes or no), and MUN grouping during the group categorization period (high or low), along with other possible confounders, as discussed below.

To address objectives 2a and 2b, questionnaires for the intervention herds were utilized to determine months during which management changes, including feed changes, were implemented in response to MUN notification and interpretation reports. However, control farms for objectives 1a and 1b were not required to complete these questionnaires (to ensure their study participation), and therefore, there was no way to confirm feed change status among control herds. Therefore, for each month during which a feed change in response to MUN data was reported in intervention herds, another intervention herd was randomly selected from herds that belonged to the same MUN group (high or low), but did not report a feed change in response to MUN data during that month, or the month preceding or following that month. This selection process created a dataset of "feed change months" during which feed changes in response to MUN data were made, and "control months" during which feed changes in response to MUN data were not made. Therefore, the definition of "intervention" for objectives 2a and 2b was the instigation of a feed change that occurred in response to MUN notification and interpretation. The definition of "control" for objectives 2a and 2b was the lack of a feed change in response to MUN notification and interpretation.

HA-MUN and S-milk were obtained for herd tests before and after the feed change months and control months. These variables for the herd tests after the reported feed change months and control months served as the outcome variable for the linear regression analyses for objectives 2a and 2b, with predictors to be investigated including: HA-MUN (2a) or S-milk (2b) for the herd test prior to the feed change months and control months; feed change (yes or no); and MUN grouping during the group categorization period (high or low), along with other possible confounders as discussed below.

For all four of the modelling processes (objectives 1a and 1b, and objectives 2a and 2b), unconditional associations between the predictors and the outcome variables were first investigated using linear regression, and those predictors that produced *P* values of less than or equal to 0.25 were offered for multivariable linear regression analyses. In the multivariable regressions, backward elimination of non-significant ($P > 0.05$) variables was conducted until the model contained only significant variables. First-order interaction variables of significant main effects were then created and offered to the model, then a similar backward elimination process for interaction variables was conducted.

For the MUN regression analyses for objectives 1a and 2a, the interaction between intervention for 1a (or feed change for 2a) and high or low MUN grouping was of particular interest for two reasons. First, MUN grouping would probably have an impact on subsequent MUN values, with herds in the high MUN group being more likely than herds in the low MUN group to have high average MUN concentrations later in the study period or after a feed change. Second, the intervention effect on MUNs was expected to occur in opposite directions within the two MUN groups (i.e. expected to lower the average HA-MUN in herds in the high MUN group with a high MUN, but increase the average HA-MUN in herds in the low MUN group with a low MUN). Therefore, in the multivariable regression analyses for MUN outcomes (objectives 1a and 2a), the intervention and MUN groupings were initially forced into the models, and the interaction between the two variables was investigated to determine the effect of the intervention in each MUN group. The interaction effect between intervention and MUN grouping on S-milk was also investigated for objectives 1b and 2b to determine if there was a difference in the potential impact of intervention between MUN groupings.

To evaluate the success of the randomized allocation of the herds, average herd characteristics (e.g. 24-hour milk yield per cow per day, MUN, parity, days-in-milk (DIM), and linear score of SCC) were calculated for each herd for the autumn period (September 2001 to November 2001) prior to the trial ("pre-trial period"). Herd averages were first calculated for each month, then an average over the three months was calculated. Pre-trial herd averages for the production variables were compared between intervention and control farms using t-tests, and found no significant differences between intervention and control farms (Table 1). However, there was a 4.4 lb (2.0 kg) numerical difference in standardized milk production between the intervention and control herds for both the high and low MUN groups, suggesting that the randomization of herd allocation did not successfully produce two completely comparable groups of farms. Therefore, subsequent analyses included MUN grouping during the group categorization period (objective 1a) or S-milk during the pre-trial period (objective 1b) as a predictor in the multiple linear regression analyses. For objectives 2a and 2b, HA-MUN and S-milk for the month before reported "feed change" and "control" months were included as a possible predictor in the multiple linear regression analyses, respectively, as mentioned earlier.

Effects of possible confounding characteristics on average HA-MUN during the final three months of the trial (objective 1a) and post-feed-change HA-MUN (objective 2a) were also investigated (e.g. average parity, average DIM, average milk production, average protein percent, average fat percent during the final three months of the trial or during the month prior to the feed change). These additional factors were not offered to the S-milk models (objectives 1b and 2b) because standard milk is already adjusted for these factors. Herd average linear score SCC was also offered to the MUN and S-milk models (objectives 1a, 1b, 2a and 2b) to control for possible confounding. The variable "herd" was included as a random effect in the models for objectives 2a and 2b (feed change) to adjust for the clustering of multiple feed changes within herds.

Goodness of fit for the final models was assessed using standard diagnostic tests. All statistical analyses were conducted in a commercial software package.[a]

Results

The final dataset for objectives 1a and 1b included 38 intervention farms and 39 control farms, with 2472

Table 1. Mean values for herd characteristics of the intervention and control groups during the pre-trial period (September to November, 2001), classified by average herd milk urea nitrogen (MUN) level.

	High MUN[a]		Low MUN[b]	
Variables	Intervention Group[c] (25 herds)	Control Group[c] (25 herds)	Intervention Group[d] (15 herds)	Control Group[d] (15 herds)
Standardized milk production (lb)	62.5	58.1	68.2	63.8
24-hour milk yield (lb/cow/d)	61.6	57.9	65.1	59.6
MUN (mg/dL)	16.7	16.6	10.3	10.4
Total milk protein (%)	3.1	3.2	3.2	3.2
Total milk fat (%)	3.7	3.6	3.7	3.8
Linear score	2.9	3.1	2.8	2.7
Parity	2.9	3.0	2.5	2.6
Days-in-milk	177	181	180	183

[a] Farms with an average herd MUN of ≥ 14.0 mg/dL during the group allocation period.
[b] Farms with an average herd MUN of ≤ 11.5 mg/dL during the group allocation period.
[c,d] There were no statistically significant differences between randomly selected intervention and control groups in either the high or low MUN groups at $P \leq 0.05$, indicating minimal response bias.

and 2331 cows (on average over the trial period), undergoing a total of 367 and 379 herd tests, respectively. Three farmers (two intervention, one control) stopped milking cows during the trial period and therefore were excluded from the analyses. Each remaining herd underwent nine to 11 monthly herd production tests per year, depending on where their herd visits fit within the calendar year. Of the 77 herds remaining in the study, 85% were in tie-stall housing and 95% fed a component ration. All herds exposed their cattle to pasture during the summer. Most herds were Holstein (six Ayrshire, two Shorthorn and one Guersey), varying in size from nine to 175 milking cows.

During the trial period, 176 of 367 intervention herd tests (48.0%) and 194 of 379 control herd tests (51.2%) had at least one subgroup of cows (one out of nine DIM by parity subgroups) within each herd with an average MUN value that was identified as abnormal (< 10 mg/dL or > 14 mg/dL). Of these, 85 (23.2%) and 72 (19.0%) were abnormally high, and 91 (24.8%) and 122 (32.2%) were abnormally low in the intervention and control herds, respectively. These abnormal MUN test results would have formed the basis for discussion regarding nutritional management between the producer and his or her nutritional advisor.

Among farms in the high MUN group, intervention farms had marginally lower mean HA-MUN values (13.8 mg/dL) than control farms (14.6 mg/dL) during the summer season ($P < 0.15$), demonstrating a potentially beneficial effect of the intervention on HA-MUNs during the time period when MUNs are usually high in PEI.[4] Examining parity-stage of lactation subgroups during this time period, early lactation cows (13.6 mg/dL vs. 14.5 mg/dL) and third-plus lactation cows (14.0 mg/dL vs. 14.9 mg/dL) had marginally ($P < 0.15$) lower mean MUN concentrations for intervention versus control farms by nearly 1 mg/dL. In particular, third-plus lactation cows in early lactation had a substantially lower mean MUN in the intervention herds (13.2 mg/dL) than in the control herds (14.8 mg/dL).

For the unconditional regression analyses of associations with mean HA-MUN during the outcome period (objective 1a), the following variables had a P value less than or equal to 0.25 (coefficient in parentheses after each variable): MUN group during the group categorization period (2.35), mean HA-MUN during the pre-trial period (0.61) and average DIM (0.013) and average linear score SCC (4.96) during the outcome period. Intervention was not significant in the unconditional regression analysis ($P = 0.62$), but this was not surprising because of the expected cancelling out of intervention effects among high and low MUN groups, as explained earlier. Effect of the intervention was assessed in the following multiple linear regression analysis results.

Results from the multiple linear regression models of associations with mean HA-MUN concentrations (objective 1a) during the outcome period are shown in Table 2. As expected, the MUN group was significantly ($P \leq 0.05$) associated with mean HA-MUN values during the last three months of the trial, but no other variables remained significant in the final model, including the interaction variable between intervention and MUN group.

For the unconditional regression analyses of associations with S-milk during the outcome period (objective 1b), the following variables had a P value ≤ 0.25 (coefficient in brackets after each variable): S-milk during the pre-trial period (0.94), MUN grouping (-2.08) and

Table 2. Final multiple linear regression model showing the impact on milk urea nitrogen (MUN) levels of interpreting MUN values outside of the normal range (intervention) for farmers and their nutritionists.

Variable	b	SE	*P*-value
Intervention	-0.22	0.81	0.79
High MUN group	1.94	0.71	0. 008
Interaction term between intervention and high MUN group	0.85	1. 02	0. 407
Constant	8.74	0.57	0.002

intervention (1.59). These variables were offered in the multi-variable regression analyses. Results for the multiple linear regression model for S-milk during the outcome period were similar to those found for mean HA-MUN during the outcome period, with S-milk before the trial being the only variable that was significant and remaining in the final model (results not shown).

In total, 35 of the 38 remaining intervention farmers responded to the questionnaire regarding use and utility of MUN test results. Among the responding farmers, 62.9% (22 of 35) indicated they did discuss their MUN results at least once with their nutrition advisor during the trial period, with nine of 13 (69%) and 13 of 22 (59%) producers in the low and high MUN groups, respectively. Among the tests for the 13 herds that did not discuss their MUN results at least once with their nutrition advisor, 43.2% were outside the normal range (16.8% high and 26.4% low). This was not significantly lower than the 50.4% of tests outside the normal range reported by producers who consulted their nutritional advisors.

Some discussions on MUN results between intervention producers and their nutritional advisors did lead to a feed change. Among the responding intervention farmers, 71.4% (25 of 35) indicated that they made a feed change during the trial period in response to MUN notification and interpretation. On these 25 farms, 54 feed changes were reported in response to the MUN notification and interpretation, and occurred during the following months: five in January, two in February, six in March, six in April, four in May, one in June, four in July, five in August, seven in September, nine in October and five in November. Of the 54 feed changes, 18 (33.3%), 22 (40.7%) and 14 (26.0%) followed from high (> 14 mg/dl), low (< 10 mg/dl) and normal (10-14 mg/dl) HA-MUN values, respectively. The 14 feed changes in response to normal HA-MUN values had a mixture of subgroups of cows (based on stage of lactation and parity), with high or low average MUNs, instigating the reported feed change.

For the unconditional regression analyses of associations with HA-MUN after a reported feed change, the following variables had a *P* value less than or equal to 0.25 (coefficient in brackets after each variable): MUN group (1.40), HA-MUN before the feed change (0.31) and feed change (intervention) (-0.61). These variables were offered to the multi-variable regression analyses. The HA-MUN before the feed change (0.23), and historical MUN group (1.52) were significant ($P \leq 0.05$) in the final model. Herds in the high MUN group did have significantly higher HA-MUN concentrations after the feed-change months compared to herds in the low MUN group, as expected, and HA-MUN before the feed change was positively associated with HA-MUN after the feed-change. HA-MUN values after feed-change months (i.e. months when feed changes were made in response to MUN notification and interpretation) were 0.61 mg/dL lower than HA-MUN values during the "no feed-change" months (matched months in other surveyed herds when feed changes were not made), but this difference was not statistically significant ($P = 0.24$; results not shown). The interaction between HA-MUN and feed-change month (intervention) was also not statistically significant.

For the unconditional regression analyses of associations with S-milk production after a reported feed change, the following variables had a *P* value less than or equal to 0.25 (coefficient in brackets after each variable): S-milk before feed change (0.85), MUN grouping (-1.80) and feed-change month (1.47). These variables were offered in the multivariable regression analyses. In the final model, S-milk for the months following feed changes was associated with a significant ($P = 0.045$) increase of 2.4 lb (1.1 kg)/cow/day, compared to months without feed changes (Table 3). S-milk was also higher for herds in the high MUN group than in the low MUN group, although this difference was not statistically significant. There was no interaction effect between intervention and MUN groupings. A small amount of the variation in S-milk existed at the herd level, with 85% of the variation occurring at the test day level.

Table 4 summarizes the responses of the dairy producers and nutritionists regarding their perceived utility and understanding of MUN reports. At the end of the trial, 22 of 35 (62.9%) producers said that they now knew how to use MUN reports, and 29 of 35 (83%) producers felt MUN was at least somewhat useful for nutritional management. All nutritionists reported that they knew how to use MUN reports, and considered them at least somewhat useful.

Discussion

To our knowledge, this is the first scientific report of a formal evaluation in commercial dairy herds of the benefits of using MUN testing for monitoring and adjusting nutritional imbalances in protein and energy. The tracking of nutritional management changes in response to MUN values, and subsequent changes in MUN and milk productivity in this randomized, controlled trial provide scientific evidence in support of anecdotal opinion that MUN testing can be a useful nutritional monitoring tool when used to instigate feed changes in response to abnormal MUN levels.

Our study showed that in herds where a feed change was made in response to MUN data, an increase of milk production of 2.4 lb (1.1 kg)/cow/day was observed in the month after the feed change. However, we cannot conclude that the increased S-milk production associated with the MUN-instigated feed change was due to the feed change and improved nutrition, for a number of reasons. First, a concurrent significant association between HA-MUN and MUN-instigated feed change was not found in the analyses for objective 2a. However, MUN-instigated feed changes were weakly associated with a reduction in HA-MUN of 0.61 mg/dL, and most of the feed changes were due to high MUNs in subgroups of cows or overall. A larger number of herds or feed changes may have provided stronger evidence that the improved milk was from reduced MUN. Experimental studies have shown that MUN values over 20 mg/dL could decrease milk production by 6.6 lb (3.0 kg)/cow/day due to the energy cost involved in converting ammonia to urea.[29]

Table 3. Final multiple linear regression model showing the impact on standard milk levels of instigating changes in feeding management in response to milk urea nitrogen interpretation.

Variable	b	SE	*P*-value
Fixed effects			
Standard milk before	0.82	0.09	0.001
Changing feed	1.07	0.54	0.045
High & low group	0.67	0.64	0.300
Constant	4.04	2.84	0.155
Random effects			
Herd	0.93	1.35	0.480

Second, we also relied on self-reporting of months when feed changes were made in response to MUN notification and interpretation, which may have suffered from misclassification bias. Poor recall may have led to omitted feed changes, or inaccurate reporting of the month, especially if it happened close to the end of one month or the start of another month. It is unlikely that these misclassifications were systematic in any way, and therefore would only lead to a bias toward the null (e.g. more likely to find no significant difference).

Additionally, the control months used for comparison with the feed-change months came from intervention farms, not control farms. Ideally, the control months would have come from control farms, but this clinical trial was the last component of a larger project on MUN, and we sensed that there was producer fatigue with the project. Therefore, to ensure that we could obtain a substantial number of farms to participate in the clinical trial, we told the potential participants that if they agreed to participate and were selected as control farms, they would have the option of not completing the questionnaire.

Finally, due to budget restrictions, we did not conduct formal nutritional assessments of the participating farms before the reported feed changes to confirm the nutritional cause of the abnormal MUN test results, or after the reported feed changes to confirm that the nutritional problem had been rectified. However, random selection of control months did go a long way toward ensuring that other factors were equal between the feed-change months and control months. Future clinical trials could include a larger number of participating farms, with feed-change information from all farms, and monthly ration evaluations before and after

Table 4. Attitudes toward milk urea nitrogen (MUN) data, as reported by dairy producers (n = 35) and nutritionists (n = 10), after a clinical trial was conducted to determine utility.

	Producer response		Nutritionist response	
	Number	%	Number	%
Do you feel that you now know how to use MUN reports?				
Yes	22	62.9	10	100.0
No	13	37.1	0	0.0
How do you feel about the MUN report as a nutritional management tool?				
5) Very useful	3	8.6	1	10.0
4) Useful	11	31.4	6	60.0
3) Somewhat useful	15	42.8	3	30.0
2) Not very useful	3	8.6	0	0.0
1) Not at all useful	3	8.6	0	0.0

feed changes when MUN averages indicate abnormal monthly tests.

Although not measured in this study, other potential benefits of MUN testing could be obtained, including foot health and reproduction. An association has been shown between high MUN levels and lower fertility,[3,19,33,34] and high urea concentrations have been found within the uterine lumen that impaired reproduction.[10] Bazeley *et al*[7] and Mason *et al*[28] also found that herds fed excessively high levels of dietary protein had a high incidence of laminitis.

The opinion part of the survey provided interesting evidence of the perceived utility of MUN testing. Participating intervention farmers received MUN notification and interpretation for nearly a year, and standard reports that included MUN results for nearly three years as part of the larger MUN research project. As a result, 63% felt they now knew how to use MUN reports, and the vast majority (83%) felt MUN testing was at least somewhat useful as a nutritional tool.

Whether the benefits of MUN monitoring are greater than the costs for a particular farm requires a review of the management and records of the farm. Producers with totally confined herds, who manage the feed harvesting, storage and inventories so that there is likely to be little variation in feed quality throughout the year and have the ration balanced according to the cows' milking performance and requirements, may have MUN values consistently in the normal range. These farms may find little benefit from the added cost of MUN testing other than the peace of mind of normal MUN results and the ability to confirm when problems arise. Conversely, MUN testing could be of great benefit to farms with substantial changes in feed quality during the year, or farms with large variation in historical average MUN values.

Most farms fall somewhere in between the two extremes portrayed above, requiring some analysis of farm management and records to determine the utility of MUN testing for each farm. A formal cost-benefit analysis would also assist in this decision-making process, but was not done as part of this study. The cost of MUN testing would be easy to estimate, typically around 25-30 cents per cow per test. An assessment of benefits would require information regarding current feeding management, milk production and records on the frequency of reproduction and lameness problems, along with estimates of what proportion of these problems could be due to undetected nutritional imbalances.

Compared to pre-trial values (objectives 1a and 1b), a number of reasons could have contributed to finding no significant differences between intervention and control farms with respect to HA-MUN values or standardized milk production during the last three months of the trial period. First, although the intervention farmers and their nutritional advisors received notification and interpretation of MUN values, follow-up action was infrequent. Of the 176 herd tests with abnormal MUN results in at least one subgroup of cows among the intervention herds, only 50 times (28.4% of the time) did intervention producers actually discuss these abnormal MUN results with their nutritional advisor, substantially reducing the possible impact of the intervention. In addition, control farmers also received MUN test results during the trial period (as a condition of funding the overall MUN research project). It is likely that a portion of these control farmers discussed their abnormal MUN test results with their nutritional advisors and made nutritional improvements, on their own initiative, that would have reduced the apparent benefit of the intervention to the intervention farmers compared to control farmers.

Second, 13 of 35 (37%) responding intervention producers said that they did not feel they understood how to use MUN test results, despite receiving MUN notifications and interpretation reports for a year, and involvement in the overall study for two earlier years. As a result, it was much less likely that these farmers would have made appropriate nutritional management changes to rectify a nutritional imbalance, thereby reducing the likelihood of a significant difference in outcome variables between intervention and control farms. Of the 13 farmers, only three (23.1%) discussed their MUN test results with their nutritional advisor, even though these 13 farms had 55 (44.0%) out of a possible 125 herd tests with abnormal MUN test results in at least one subgroup of cows, which was comparable with the other 25 intervention farms.

Finally, the small number of farms in the study had a limited power to detect any significant differences if they existed. However, the number of farms was intentionally limited, for logistical and budgetary reasons, to those that would likely have abnormal average MUN values during the trial, based on the monitoring period prior to the trial.

Conclusions

In dairy herds making a feed change in response to MUN notification and interpretation reports, an increase in standardized milk production of 2.4 lb (1.1 kg)/cow/day was observed in the month after the feed change. Results are based on comparisons with randomly selected herds not making a feed change during the same time period, while controlling for possible confounders and clustering of feed changes within herds. There was no significant difference in milk production or MUN values between intervention and control farms at the end of the trial, indicating that farmers cannot expect improvements in milk production or MUN values unless they apply the MUN information to make feed changes. By the end of the study, most producers and all nutritionists felt they knew how to use MUN reports, and felt that MUN testing was at least somewhat useful as a nutritional tool.

Endnote

[a] STATA, version 9.0; Stata Corporation, College Station, Texas.

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