International Journal of Agricultural and Environmental Information Systems
Volume 9 • Issue 3 • July-September 2018

Implementation of CTR Dairy Model Using the Visual Basic for Application Language of Microsoft Excel

A. Ahmadi, University of California Davis, Davis, USA
P. H. Robinson, University of California Davis, Davis, USA
F. Elizondo, Universidad de la República, Montevideo, Uruguay
P. Chilibroste, Universidad de la República, Montevideo, Uruguay

ABSTRACT

The goal of the article is to implement the CTR Dairy model using the Visual Basic for Application (VBA) language of Microsoft Excel. CTR Dairy is a dynamic simulation model for grazing lactating dairy cows that predicts milk production and profit over feeding based on ruminal digestion and absorption of nutrients under discontinuous feeding schedules. The CTR Dairy model was originally developed as a research tool using a proprietary computer simulation software called SMART that required the SMART client to run the program. As SMART software is now discontinued, and its client is no longer available, rewriting the model in the VBA language using Microsoft Excel for inputs and outputs makes the program available to a broad range of users including dairy farmers, extension advisors, dairy nutrition consultants and researchers. Dairy farmers can use the new version of the CTR Dairy program to manipulate the herbage allowance and the access time to the grazing paddock, as well as the timing of supplemental feeding, to improve the utilization of the pasture and to increase the production of the milk.

KEYWORDS

Dairy Cattle, Discontinuous Feeding Systems, Feeding Schedule Evaluation, Grazing System, Modeling, Ration Evaluation

INTRODUCTION

CTR Dairy is a dynamic simulation model for grazing lactating dairy cows that predicts milk production and profit over feeding based on ruminal digestion and absorption of nutrients under discontinuous feeding schedules. The following biological background is based on Chilibroste (2008). While most rumen simulation models assume relatively 'steady state' conditions, the practical need for models that can represent discontinuous feeding regimes, caused by not feeding cattle totally mixed rations (TMR) that cause rumen pool sizes to vary with time of the day, was highlighted (Dijkstra et al., 2005). Compared with continuous feed input, discontinuous feeding may result in distinctly different profiles of non-glucogenic to glucogenic volatile fatty acids (VFA) and rumen pH values

DOI: 10.4018/IJAEIS.2018070105

that could temporarily negatively affect fiber degradation. Moreover, deviations from widely used Monod-equations, that represent microbial substrate utilization and growth in most metabolic models, may be transient conditions of the rumen ecosystem (Dijkstra et al., 2002).

In modern dairy management systems, it has become common to offer cows feed on an ad libitum basis. Confined cows are often kept in loose housing systems and, to prevent feed selection, are offered a TMR. Thus, feed intake becomes relatively independent of individually expressed intake behavior as the management objective is to make intake behavior a function of the diet, rather than of the animal. This contrasts to foraging cattle, where animal selection is integral to behaviour. Providing nutritionally balanced diets for foraging cattle is generally achieved by supplementing pasture with feed supplements at various times of the day. Cattle foraging behavior, and their strategies to obtain a balanced nutrient profile in pastoral ecosystems, are determined by their short and long-term physiological state, pasture availability, as well as the feeding level and type of supplements (Chilibroste et al., 2005). Feed intake behavior of cattle is characterized by alteration, during the day, of eating, rumination, rest and social activities (Gibb et al., 1997). Factors that control eating and grazing time are less well understood than factors that control intake rate, such as bite mass, time per bite and the ratio between prehension and manipulation of jaw movements (Chilibroste, 1999; Laca et al., 1994). Whereas short-term changes in metabolizable energy supply and gut fill are probably involved in controlling meal size and frequency, it is longterm signals, such as changes in body energy stores that influence dry matter (DM) intake. The role of learning on DM intake control was highlighted by Provenza (1995), although total DM intake and diet selection at grazing are mediated by different foraging strategies that result from integration by cattle of short and long-term information (Forbes, 1995), suggesting a very complex process.

To represent and predict the unique processes of ingestion and digestion under discontinuous feeding situations, such as grazing, it is essential that a rumen model simulate the resulting diurnal fermentation processes. Recently, results of a series of grazing experiments that varied the allowed grazing time, as well as the combinations of rumen fill and fasting length before grazing, were used to evaluate a mechanistic, dynamic model (Chilibroste et al., 2001) that aimed to predict digestion and absorption of nutrients, and was based on a previously developed model (Dijkstra et al., 1996), in which cattle were fed sugarcane based diets. The increase in prediction error with increased length between two consecutive meals (Chilibroste et al., 2001), highlighted the need for diurnal definition of model parameters, such as fractional passage and degradation rates, and the dynamics and kinetics of soluble feed fractions in the rumen.

The CTR Dairy model was originally developed as a research tool using a proprietary computer simulation software called SMART that required the SMART client to run the program. As SMART software is now discontinued, and its client is no longer available, rewriting the model in the Visual Basic for Application (VBA) language using Microsoft Excel for inputs and outputs makes the program available to a broad range of users including dairy farmers, extension advisors, dairy nutrition consultants and researchers.

As its name suggests, the VBA language is closely related to Visual Basic and uses the Visual Basic Runtime Library. However, VBA code can only run within a host application such as Excel, rather than as a stand-alone program. Code written in VBA is compiled to Microsoft P-Code (packed code), which the host application (Excel) stores as a separate stream in its files (e.g., .xlsx, .xlsm). The intermediate code is then executed by a virtual machine (hosted by the host application). CTR Dairy saves data in text files encoded using the Extensible Markup Language (XML). These data files are both human-readable and machine-readable and also the CTR Dairy program to interact with other programs written in other programing languages.

As CTR Dairy does not formulate a ration, the user must first use a ration formulation program such as PC Dairy (Ahmadi et al, 2013) to formulate a least cost ration, and then use the unique feature of CTR Dairy to find the best feeding schedule to optimize milk production and to maximize profit over feeding.

Our goal is to implement the CTR Dairy model using the VBA language of Microsoft Excel as a decision-making tool. CTR Dairy a simulation model that aims to function under non-steady state conditions in order to allow prediction of nutrient availability in dairy cows managed under discontinuous feeding systems. The ultimate aim of this model is to provide scientists and advisers a sound tool to evaluate actual feeding strategies, as well as facilitate research on new ones.

CTR DAIRY MODEL DESCRIPTION

The following model description is based on Chilibroste (2008). The original model is an advanced version of the mechanistic and dynamic non-steady state rumen model of Chilibroste et al. (2001). New elements in the model include inclusion of chewing activities, a discrete lag time to represent the delay before rumen fermentation or passage can occur, as well as diurnal variation in rumen DM content (DMC), rumen pH and in fractional degradation rates of neutral detergent fibre (NDF) and rumen VFA absorption. The current model was built to operate with up to three discrete feeds, where pasture is defined as a feed, which can be offered in independent patterns to groups of cows. The expanded version of the model has 42 state variables, 30 of which deal with insoluble feed fractions, 8 with soluble feed fractions and 4 are the rumen pools of ammonia, VFA, long chain fatty acids and microbial mass.

Although the underlying motivation to build the model came from dairy systems in which cows are grazed, and supplemented with forages(s) and/or concentrates (e.g., Chilibroste et al., 2003; Mattiauda et al., 2003), it can also function under a wide range of other feeding conditions in which cattle have unlimited access to feed. For example, feeding strategies that use grazed forage, silage or hay, supplements and concentrates fed at different times of the day, as well as TMR, can be evaluated. In the case of TMR feeding, the model provides up to three feed components of the TMR as the different feeds. Model outputs are the predicted rumen metabolite concentrations (including pH), rumen pool sizes of several defined fractions (including water), and absorption of classes of nutrients (i.e., glycogenic, aminogenic, lipogenic) at the rumen and intestinal level.

Software Description

The CTR Dairy program is written in VBA language that uses Microsoft Excel's worksheets for input and output. Figure 1 shows the main menu of the program, which allows the user to enter input information, run the simulation, and view the outputs. To describe the program we use an example of Holstein dairy cows grazing on a legume pasture twice a day and being fed a mixed diet and a supplement twice a day.

Input Module

The user starts by entering animal information such as body weight, milk fat, protein and lactose proportions, milk price, number of cows in milk and daily body change. The user can then specify the same feeds used in the ration formulation, because both CTR Dairy and PC Dairy share a common feed library which contains 102 feeds with the same name and number. Finally, the user specifies amounts of feeds provided at any hour of the day up to 24 times daily.

Animal Information

The user uses the 'Animal Information' tab (Figure 2) to enter animal body weight, milk fat, protein and milk proportions, milk price, number of cows in milk, body weight change and rumen liquid passage rate. In our example, the body weight is 645 kg and the milk fat, protein, and lactose are 3.9, 3.4 and 5.0%, respectively. The milk price is 0.30 US dollars per liter and there are 1000 cows in milk that do not gain or lose any body weight. The rumen liquid passage rate is usually about 0.12 1/h.

Figure 1. Main Menu Screen

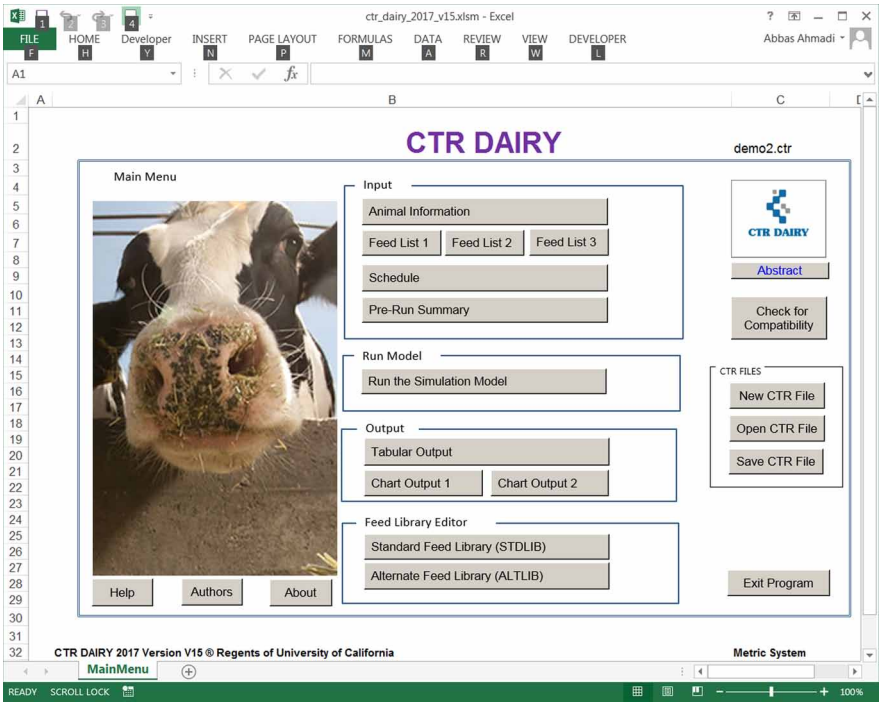
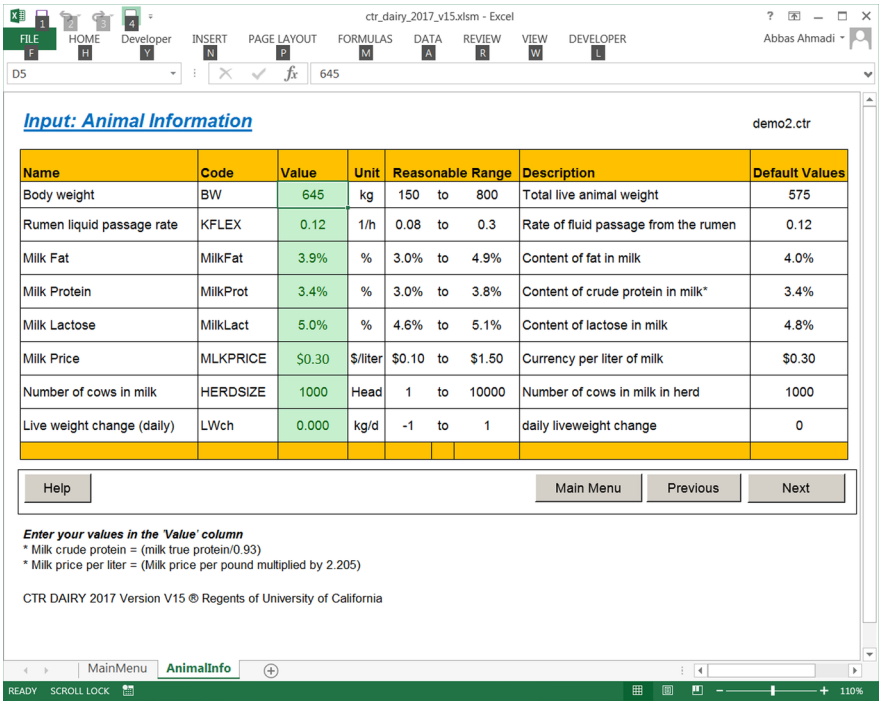


Figure 2. Animal Information Screen



Name	Code	Value	Unit	Reasonable Range			Description	Default Values
Body weight	BW	645	kg	150	to	800	Total live animal weight	575
Rumen liquid passage rate	KFLEX	0.12	1/h	0.08	to	0.3	Rate of fluid passage from the rumen	0.12
Milk Fat	MilkFat	3.9%	%	3.0%	to	4.9%	Content of fat in milk	4.0%
Milk Protein	MilkProt	3.4%	%	3.0%	to	3.8%	Content of crude protein in milk*	3.4%
Milk Lactose	MilkLact	5.0%	%	4.6%	to	5.1%	Content of lactose in milk	4.8%
Milk Price	MLKPRICE	$0.30	$/liter	$0.10	to	$1.50	Currency per liter of milk	$0.30
Number of cows in milk	HERDSIZE	1000	Head	1	to	10000	Number of cows in milk in herd	1000
Live weight change (daily)	LWch	0.000	kg/d	-1	to	1	daily liveweight change	0

Feed Lists

Feeds in CTR are divided into three feed lists: Feedlist 1 contains pasture feeds, Feedlist 2 contains mixed feeds, and Feedlist 3 contains supplement feeds. However, any combination of feedstuffs can be used to create any feed list. The user can also change the names of the feed lists.

For each feed list the user adds their needed feeds (up to 20 total feeds) from the Standard or Alternate feed libraries. The user can modify any nutritive values in their selected feeds, but the user must enter the price for each feed and its amount in this feed list, with all feeds adding to 100% (in E27). Calculated average values for the feed lists are listed in the grey cells below the list of feeds in the feed list (Figure 3).

Feeding Schedule

The user specifies the amount and time of feeding for three feed lists in the daily feeding schedule tab (Figure 4). Feeds provided at any hour of the day is assumed to be eaten over 60 minutes. Use of all three feed lists is not required, but those that are selected can be fed up to 24 times per day. Feedlist names come from the 'Feedlist' tabs and the user can change names in those tabs if desired. In our example, the first grazing session on the legume pasture starts at 8:00 am and ends at noon. The second grazing session starts at 5:00 pm and ends at 7:00 pm. The total pasture intake is 8.05 kg per day per head. The first supplementation in the amount of 4.72 kg is given at 6:00 am and the same supplementation for the same amount is given for the second time at 8:00 pm for a total of 9.44 kg per day per head. The first corn silage diet in the amount of 3.86 kg is given at 3:00 pm and the same diet in the amount of 2.57 kg is given for the second time at 9:00 pm for a total of 6.44 kg per day per head. The daily intake is 23.92 kg per head.

Figure 3. Feed List Screen

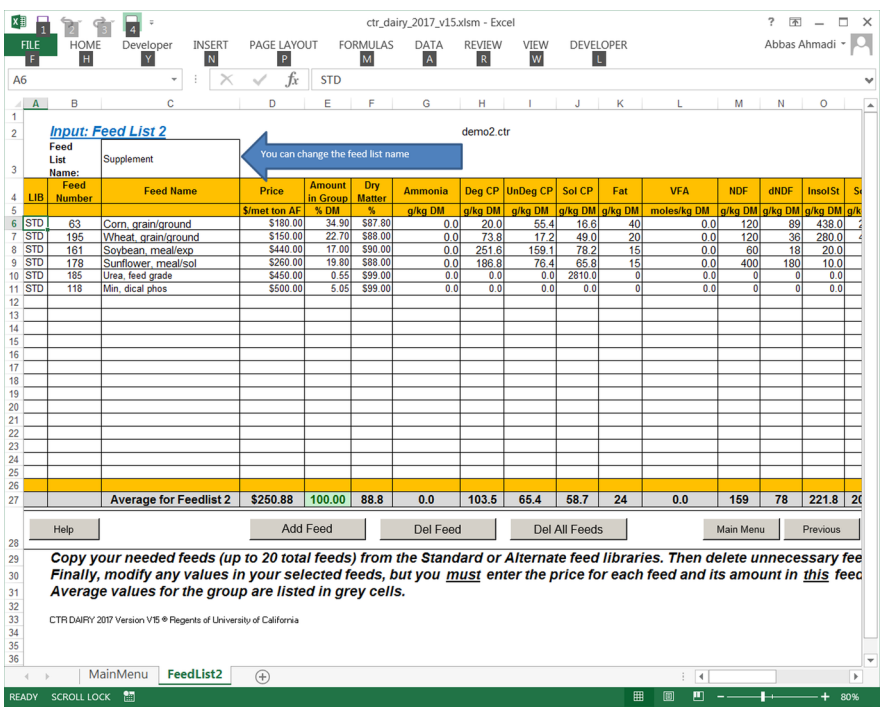
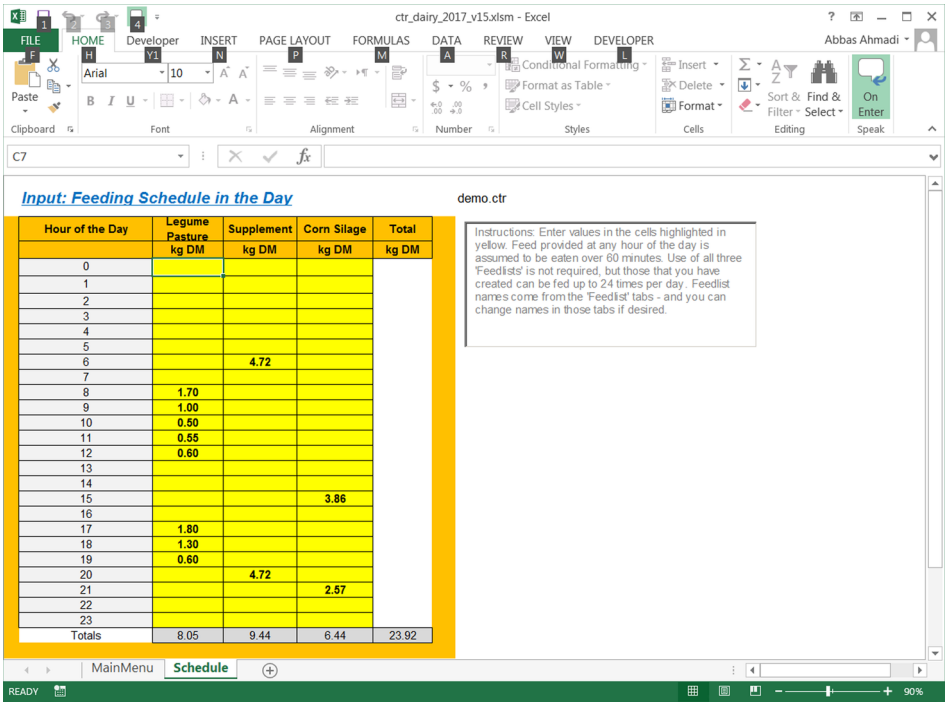


Figure 4. Feeding Schedule Screen



Hour of the Day	Legume Pasture kg DM	Supplement kg DM	Corn Silage kg DM	Total kg DM
0				
1				
2				
3				
4				
5				
6		4.72		
7				
8	1.70			
9	1.00			
10	0.50			
11	0.55			
12	0.60			
13				
14				
15			3.86	
16				
17	1.80			
18	1.30			
19	0.60			
20		4.72		
21			2.57	
22				
23				
Totals	8.05	9.44	6.44	23.92

The user can change the feeding schedule and re-run the simulation model to determine effects of changes in the feeding schedule on milk production, profit projection and other key outputs. This is a key, and unique, feature of the CTR Dairy program.

Execution Module

The ruminal digestion and absorption of nutrients under discontinuous feeding schedules are calculated based on the original 2008 version of CTR Dairy (Chilibroste et al., 2008), but with the addition of the ability to predict milk production and profit over feeding. The program runs a simulation for 7 days and, in each day, it simulates rumen dynamics minute by minute a total of 1,440 times, or 10,080 times in the 7 days.

Output Module

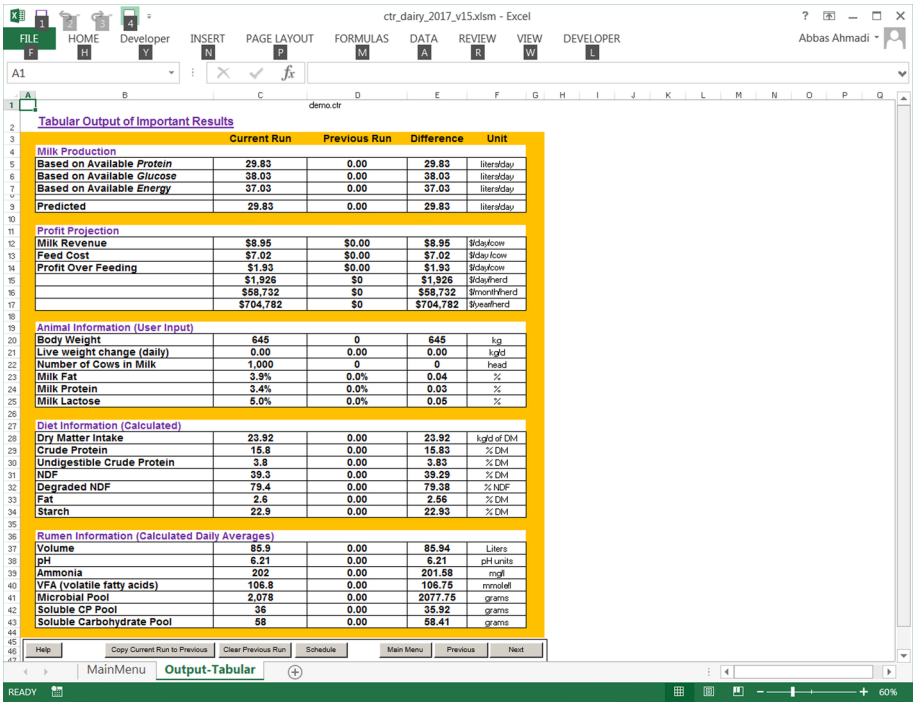
The output tab (Figure 5) shows milk production, profit projection and other key parameters. For our sample herd, the program predicts 29.83 liters of milk per day per cow. Although the milk production can be as high as 37.03 liters based on the amount of available energy, but the limiting factor in milk production is the amount of available protein. The milk revenue is 8.95 USD per day per head, the feed cost is $7.02 USD per day per head and the profit over feeding is $1.93 per day per head.

The program also plots the key rumen parameters such as volume, pH, soluble crude protein pool, soluble carbohydrate pool, liquid pool, microbial pool, volatile fatty acid, and ammonia over hours of day (Figures 6 and 7).

Data Files

CTR Dairy uses the Extensible Markup Language (XML) to encode and save data files. Figure 8 shows a section of the XML file that stores the animal information data. The name, value and unit

Figure 5. Output Screen of CTR Dairy Program in a Tabular Format



demo.ctr

Tabular Output of Important Results

	Current Run	Previous Run	Difference	Unit
Milk Production				
Based on Available *Protein*	29.83	0.00	29.83	liters/day
Based on Available *Glucose*	38.03	0.00	38.03	liters/day
Based on Available *Energy*	37.03	0.00	37.03	liters/day
Predicted	29.83	0.00	29.83	liters/day
Profit Projection				
Milk Revenue	$8.95	$0.00	$8.95	$/day/cow
Feed Cost	$7.02	$0.00	$7.02	$/day/cow
Profit Over Feeding	$1.93	$0.00	$1.93	$/day/cow
	$1,926	$0	$1,926	$/day/herd
	$58,732	$0	$58,732	$/month/herd
	$704,782	$0	$704,782	$/year/herd
Animal Information (User Input)				
Body Weight	645	0	645	kg
Live weight change (daily)	0.00	0.00	0.00	kg/d
Number of Cows in Milk	1,000	0	0	head
Milk Fat	3.9%	0.0%	0.04	%
Milk Protein	3.4%	0.0%	0.03	%
Milk Lactose	5.0%	0.0%	0.05	%
Diet Information (Calculated)				
Dry Matter Intake	23.92	0.00	23.92	kg/d of DM
Crude Protein	15.8	0.00	15.83	% DM
Undigestible Crude Protein	3.8	0.00	3.83	% DM
NDF	39.3	0.00	39.29	% DM
Degraded NDF	79.4	0.00	79.38	% NDF
Fat	2.6	0.00	2.56	% DM
Starch	22.9	0.00	22.93	% DM
Rumen Information (Calculated Daily Averages)				
Volume	85.9	0.00	85.94	Liters
pH	6.21	0.00	6.21	pH units
Ammonia	202	0.00	201.58	mg/l
VFA (volatile fatty acids)	106.8	0.00	106.75	mmol/l
Microbial Pool	2,078	0.00	2077.75	grams
Soluble CP Pool	36	0.00	35.92	grams
Soluble Carbohydrate Pool	58	0.00	58.41	grams

Figure 6. Diurnal plots of Key Rumen Parameters (Rumen Volume, Soluble CP Pool, Soluble Carbohydrate Pool, and Liquid Pool) over the Day

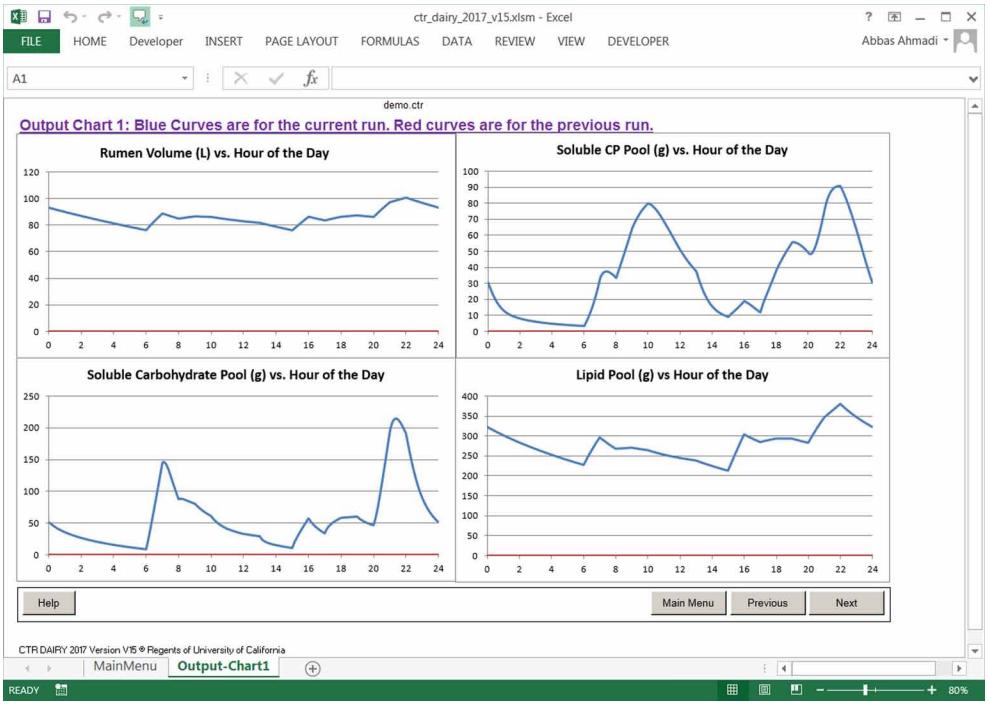


Figure 7. Diurnal plots of Key Rumen Parameters (pH, VFA, Ammonia, and Microbial pool) over the Day

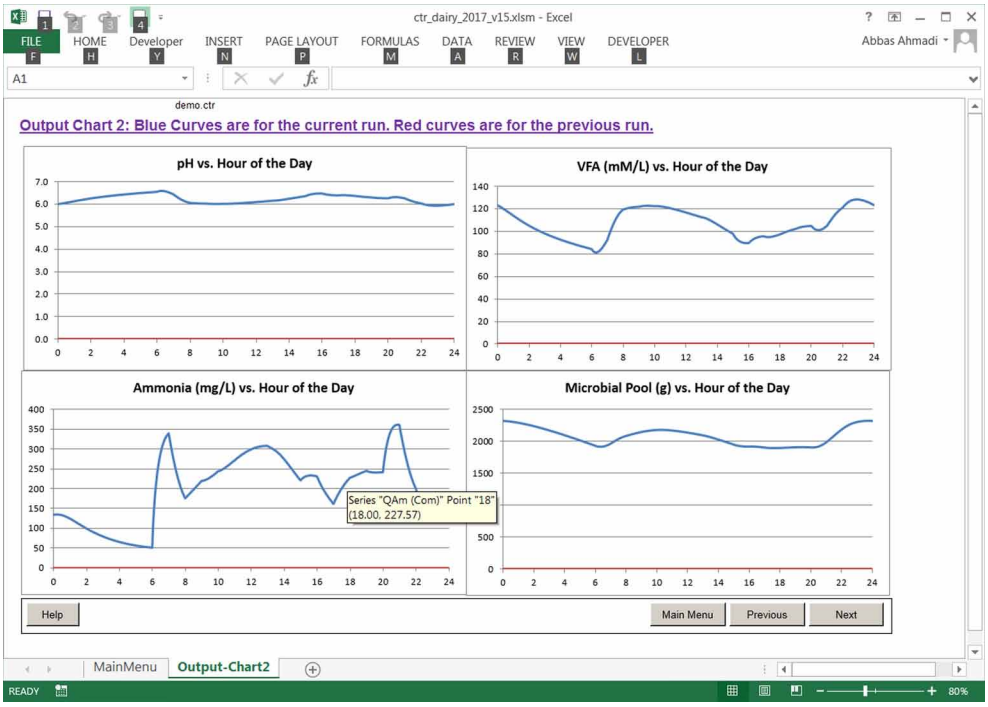
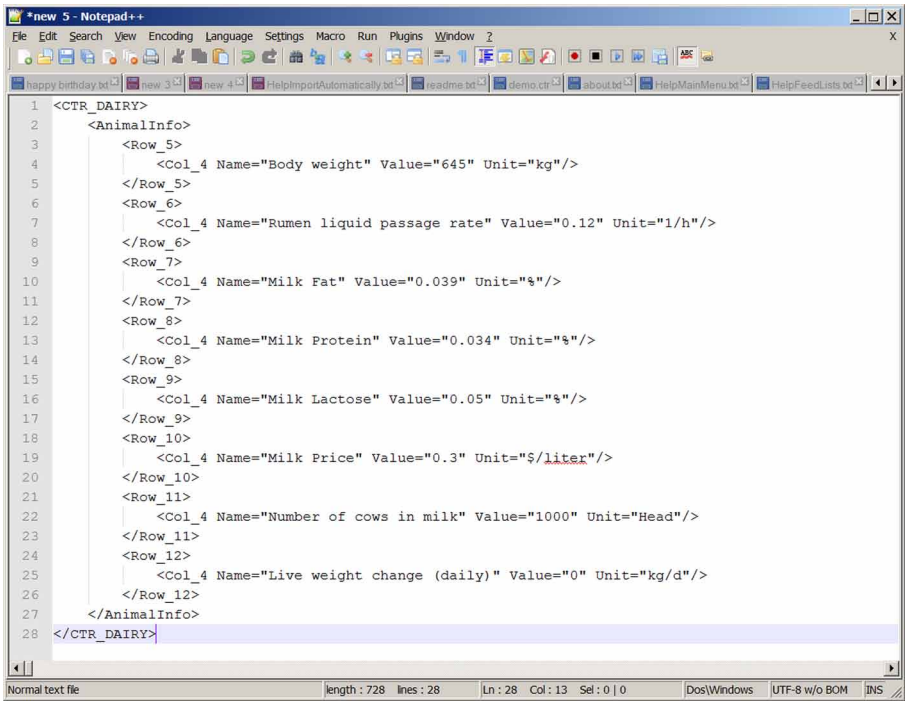


Figure 8. CTR Dairy data file encoded using XLM format



```
<CTR_DAIRY>
    <AnimalInfo>
        <Row_5>
            <Col_4 Name="Body weight" Value="645" Unit="kg"/>
        </Row_5>
        <Row_6>
            <Col_4 Name="Rumen liquid passage rate" Value="0.12" Unit="1/h"/>
        </Row_6>
        <Row_7>
            <Col_4 Name="Milk Fat" Value="0.039" Unit="%"/>
        </Row_7>
        <Row_8>
            <Col_4 Name="Milk Protein" Value="0.034" Unit="%"/>
        </Row_8>
        <Row_9>
            <Col_4 Name="Milk Lactose" Value="0.05" Unit="%"/>
        </Row_9>
        <Row_10>
            <Col_4 Name="Milk Price" Value="0.3" Unit="$/liter"/>
        </Row_10>
        <Row_11>
            <Col_4 Name="Number of cows in milk" Value="1000" Unit="Head"/>
        </Row_11>
        <Row_12>
            <Col_4 Name="Live weight change (daily)" Value="0" Unit="kg/d"/>
        </Row_12>
    </AnimalInfo>
</CTR_DAIRY>
```

of each parameter are stored in a pair of pointed bracket. For example, line 4 shows the value of 645 kg for the body weight. This encoding is both human and machine-readable thereby allowing CTR Dairy to interact with other programs written in other programing languages.

BIOLOGICAL INTERPRETATION OF OUTPUTS

The rumen is essentially a fermentation chamber where plant fiber is broken down into smaller digestible components by bacteria and other microbes. To represent and predict the unique processes of ingestion and digestion under discontinuous feeding situations, such as grazing, it is essential that a rumen model simulate the resulting diurnal fermentation processes. Figures 6 and 7 show the plots of the key rumen parameters such as volume, pH, soluble crude protein pool, soluble carbohydrate pool, liquid pool, microbial pool, volatile fatty acid, and ammonia are plotted over hours of day.

The first plot in Figure 6 shows the diurnal plot of rumen volume over the day. The capacity of an adult dairy cow's rumen is about 184 liters. In our example herd, the rumen volume ranges from 78 to 100 liters. The plot shows a raise at 6:00 am when the first supplemental diet is given and another smaller raise at 8:00 am when the first grazing session is started. The third raise in the plot appears at 3:00 pm when the corn silage diet is given. The fourth, fifth, and sixth raises appear at 5:00 pm, 8:00 pm, and 9:00 pm corresponding to the timing of the afternoon grazing session, the afternoon supplemental diet, and the evening corn silage diet, respectively.

The second plot in Figure 6 shows the diurnal plot of soluble crude protein pool over the day. In our example herd, the soluble CP pool ranges from 1 to 90 grams. At 6:00 am, just before the first supplemental diet is given, the curve is at its lowest level due to night fasting. The curve raises rapidly once the supplemental diet is given. It raises again at 8:00 am when the morning grazing session starts. It raises for the third time at 3:00 pm when the corn silage diet is given, and for the fourth time at 5:00 pm when the afternoon grazing session is started, and for the fifth time at 8:00 pm when the afternoon supplemental diet is given. The soluble CP pool keeps raising when the evening corn silage diet is given at 9:00 pm. It reaches its peak at 11 pm and then starts dropping until it reaches its lowest level at 6:00 am, just before the first supplemental diet is given.

The third plot in Figure 6 shows the diurnal plot of soluble carbohydrate pool over the day. In our example herd, it ranges from 1 to 90 grams. Carbohydrate is the major component of ruminant diets and it differs widely in the rate and extent of fermentability in the rumen. In forage-based diets the cell wall polysaccharides (structural carbohydrates) are the primary source of energy whereas in cereal based diets the storage polysaccharides (starch and fructosans) provide most of the energy requirements. Microbes convert both the cell wall and storage polysaccharides to five and six carbon sugars. These sugars are rapidly fermented into SCFA and can provide up to 70% of the energy requirements of the cow (Fellner, 205).

The fourth plot in Figure 6 shows the diurnal plot of liquid pool over the day. In our example herd, it ranges from 200 to 400 grams and follows the same pattern of fluctuations as of the soluble CP pool.

The first plot in Figure 7 shows the diurnal plot of rumen pH over the day. In our example herd, the pH ranges from 6.0 to 6.8. A high pH (> 7) is seen on poor quality forage diets supplemented with urea. In high-producing dairy cows, acidosis (rumen pH < 6.0) is a common problem. This occurs when the cow eats too much rapidly digestible starch or sugar that creates acid and overwhelms the rumen's buffering system. Most of the buffer in the rumen comes in the form of saliva that is generated when the cow chews her cud. Inadequate intake of long fiber that promotes rumination (cud-chewing) can also result in acidosis because it provides less salivary buffer to counteract the acid produced by grain fermentation. The rumen microbes, especially those that primarily digest fiber, are acid intolerant. They do not grow well in acid and they don't digest feed, especially forages, well under acid conditions (de Ondarza, 2000). In our example herd, the rumen pH is at its peak at 6:00 am due to the night fasting. It drops rapidly when the first supplemental diet is given at 6:00 am. By 8:00 am the rumen pH approaches the acidosis level of about 6.0, but it raises again when the first grazing

session starts at 8:00 am. Each time a supplement diet or a corn silage dies is given, the rumen pH drops, and each time a grazing session starts, the rumen pH raises. Dairy farmers can use this plot to avoid the acidosis problem in their herds.

The second plot in Figure 7 shows the diurnal plot of the rumen VFA (Volatile Fatty Acid) pool over the day. The rumen provides a site where the rumen microorganisms can digest carbohydrates, proteins, and fiber. Through this digestion process, energy or volatile fatty acids (VFA's) and microbial protein are produced (Penn State University, 2017). VFA are actually waste products from the rumen microbes but the cow absorbs them from her rumen and uses them as major source of energy. In our sample herd, the VFA ranges from 80 to 130 mM/L. At 6:00 am, just before the first supplemental diet is given, the curve is at its lowest level due to night fasting. The curve raises rapidly once the supplemental diet is given at 6:00 am. It raises slightly at 8:00 am when the morning grazing session starts. Then it drops slowly and reaches its second minimum at 3:00 pm, just before the corn silage diet is given. The curve keeps raising during the afternoon grazing session at 5:00 pm, the afternoon supplemental diet at 8:00 pm, and the evening corn silage diet at 9:00 pm. It reaches its peak at 11 pm and then starts dropping until it reaches its lowest level at 6:00 am, just before the first supplemental diet is given.

The third plot in Figure 7 shows the diurnal plot of the rumen ammonia over the day. Ammonia is the most important source of nitrogen for protein synthesis in the rumen. Ammonia concentration in the rumen can fluctuate between < 17 mg/L (low protein roughage) and as high as 680 mg/L following feeding of rapidly degraded protein (Fellner, 2005). Many microbes that use ammonia can also use amino acids or peptides. The use of ammonia is reduced in the presence of amino acids and peptides explaining the variability in ammonia concentrations in the rumen. In our example herd, the rumen ammonia ranges from 50 to 350 mg/L and follows the same pattern of fluctuations as of the soluble CP pool.

The fourth plot in Figure 7 shows the diurnal plot of the microbial pool over the day. Ruminants, such as cattle, rely upon a rich and diverse community of symbiotic ruminal microbes to digest their feed. These symbionts are capable of fermenting host-indigestible feed into nutrient sources usable by the host, such as volatile fatty acids. The host requires ruminal fermentation products for body maintenance and growth and milk production (Kelsea et al, 2015). In our example herd, the microbial pool ranges from 1800 to 2400 g and follows the same pattern of fluctuations as of the soluble CP pool.

DISCUSSION AND CONCLUSION

An important feature of the new version of CTR Dairy program compared to other dairy cattle feeding programs is its unique ability to predict milk production and profit over feed cost based on the timing of grazing sessions and supplement feeding. To demonstrate the economic impact of using the CTR Dairy as a decision support tool, the simulation program is run by two scenarios as described below.

In the first scenario, a herd of 1000 cows in milk is grazed once a day for three hours from 7:00 am to 10:00 am on a legume pasture. The dry matter intake from grazing is 6.60 kg/cow/day. A supplemental feed, in the form of a corn concentration, is given twice a day at 5:00 am and 3:00 pm at the rate of 3.05 kg/cow/feeding. Another supplemental feed, in the form of a corn silage, is given once a day at 4:00 pm at the rate of 4.30 kg/cow/feeding. The cow body weight is 550 kg and the body weight loss is 0.3 kg/day. Milk has 3.7% fat, 3.0% protein, and 4.9% lactose. Milk price is $0.30/litter. The legume pasture costs $35.0/metric ton As Fed, the corn concentration costs $120/metric ton As Fed, and the corn silage costs $80/metric ton As Fed.

Running the simulation with the first scenario with the feed intake of 17.0 kg/cow/day and the feed cost of $4.08/cow/day, predicts a milk production of 23.65 litter/cow/day with a milk revenue of $7.10/cow/day. The profit over feeding is $3.012 /day/cow or $3,012/day/herd or $1,102,239/year/herd.

In the second scenario, all the input information, including cow body weight, cow body loss, milk composition, milk price, feed intake, feed cost, and feeding schedule is the same as in the first

scenario except the supplemental feed in the form of a corn silage is given at 9:00 am instead of 4:00 pm at the same rate of 4.30 kg/head/feeding.

Running the simulation with the second scenario with the same feed intake of 17.0 kg/cow/day and the same feed cost of $4.08/cow/day, predicts a different milk production of 24.23 litter/cow/day with a different milk revenue of $7.27/cow/day. The profit over feeding is $3.186/day/cow or $3,186/day/herd or $1,166,245/year/herd. A single change in the feeding schedule (giving the corn silage supplemental feed at 9:00 am instead of 4:00 pm) increases the profit over feeding from $1,102,239/year/herd to $1,166,245/year/herd, a difference of $64,006/year/herd.

Dairy farmers can use the new version of the CTR Dairy program to manipulate the herbage allowance and the access time to the grazing paddock, as well as the timing of supplemental feeding, to improve the utilization of the pasture and to increase the production of the milk. Dairy nutrition consultants can use the plots of the key rumen parameters as diagnostic tools for the ingestion and digestion processes in grazing dairy cows.

In terms of software engineering, using Microsoft Excel with its embedded VBA language for implementing the CTR Dairy model has several advantages: (1) The Excel software is widely available and intended users are mostly familiar with its operation; (2) Excel worksheets can be used for input screens and output tables and plots with minimal coding; (3) The Excel worksheets can also be used to store and manage feed libraries needed for the simulation program; (4) Advanced users can easily add new worksheets and plots to the output module using the familiar Excel menu; (5) The VBA language, embedded in Excel, is a full-featured programming language that can be used to rapidly implement a simulation model and make it available to a broad range of audiences without the need for a proprietary simulation software package.

ACKNOWLEDGMENT

We are planning to add an expert system module to the program to interpret outputs and give advice to farmers. We are also planning to expand the feed library database to include more feeds from other countries. Correspondence concerning this article should be addressed to Abbas Ahmadi, Department of Animal Science, University of California Davis, 1 Shields Ave, Davis, California, USA. Email: abahmadi@ucdavis.edu. The manuscript is an extended version of the EFITA 2017 submission and is prepared for publication in International Journal of Agricultural and Environmental Information Systems (IJAEIS).

REFERENCES

Ahmadi, A., Robinson, P. H., & Chilibroste, P. (2013, June). Pcdairy Enterprise: A computer package for formulation and evaluation of rations for dairy cattle. *Paper presented at the meeting of the World Congress of Computers in Agriculture and Natural Resources (EFITA-WCCA-CIGR)*, Turin, Italy.

Chilibroste, P. (1999). Grazing time: the missing link. A study of the plant–animal interface by integration of experimental and modelling approaches [PhD Thesis]. Wageningen, The Netherlands.

Chilibroste, P., Bachetta, C., Etchegaray, S., Ferreira, I., Lockhart, C., & Pose, L. (2003). Effect of corn silage and grazing strategy on rumen pool sizes of grazing dairy cows. In *IX World Conference on Animal Production and XVIII Reuniao Lationamericana de Producao Animal*, Porto Alegre, Brazil (p. 31).

Chilibroste, P., Dijkstra, J., Robinson, P. H., & Tamminga, S. (2008). A simulation model "CTR Dairy" to predict the supply of nutrients in dairy cows managed under discontinuous feeding patterns. *Animal Feed Science and Technology*, *143*(1-4), 148–173. doi:10.1016/j.anifeedsci.2007.05.009

Chilibroste, P., Dijkstra, J., & Tamminga, S. (2001). Design and evaluation of a non-steady state rumen model. *J. Agric. Sci.*, *49*, 297–312.

Chilibroste, P., Gibb, M. J., & Tamminga, S. (2005). Pasture characteristics and animal performance. In J. Dijkstra, J. M. Forbes, & J. France (Eds.), *Quantitative Aspects of Ruminant Digestion and Metabolism* (pp. 681–706). Wellington, UK: CABI Publishing. doi:10.1079/9780851998145.0681

de Ondarza, M. B. (2000). The stomach of the dairy cow. Retrieved June 20, 2017 from http://www.milkproduction.com/Library/Scientific-articles/Animal-health/The-stomach-of-the-dairy-cow/

Dijkstra, J., France, J., Neal, H. D. S. C., Assis, A. G., Aroeira, L. J. M., & Campos, O. F. (1996). Simulation of digestion in cattle fed sugarcane: Model development. *J. Agric. Sci.*, *127*(02), 231–246. doi:10.1017/S0021859600078011

Dijkstra, J., Kebreab, E., Bannink, A., France, J., & Lopez, S. (2005). Application of the gas production technique in feed evaluation systems for ruminants. *Animal Feed Science and Technology*, *123/124*, 561–578. doi:10.1016/j.anifeedsci.2005.04.048

Dijkstra, J., Mills, J. A. N., & France, J. (2002). The role of dynamic modelling in understanding the microbial contribution to rumen function. *Nutrition Research Reviews*, *15*(01), 67–90. doi:10.1079/NRR200237 PMID:19087399

Fellner, V. (2005). Rumen microbes and nutrient management. *NCSU*. Retrieved June 20, 2017 from https://projects.ncsu.edu/project/swine_extension/swinereports/2004-2005/dairycattle/nutrition/fellner1.htm

Forbes, J. M. (1995). *Voluntary Food Intake and Diet Selection in Farm Animals*. Wallingford, UK: Wallingford CAB Int.

Gibb, M. J., Huckle, C. A., Nuthall, R., & Rook, A. J. (1997). Effect of sward surface height on intake and grazing behaviour by lactating Holstein Friesian cows. *Grass and Forage Science*, *52*(3), 309–321. doi:10.1111/j.1365-2494.1997.tb02361.x

Kelsea, A. J., Caroline, A. M., Christine, L. O., Paul, J. W., & Garret, S. (2015). Ruminal bacterial community composition in dairy cows is dynamic over the course of two lactations and correlates with feed efficiency. *Applied and Environmental Microbiology*, *81*(14), 4697–4710. doi:10.1128/AEM.00720-15 PMID:25934629

Laca, E. A., Ungar, E. D., & Demment, M. W. (1994). Mechanisms of handling time and intake rate of a large mammalian grazer. *Applied Animal Behaviour Science*, *39*(1), 3–19. doi:10.1016/0168-1591(94)90011-6

Mattiauda, D. A., Tamminga, S., Elizondo, F., & Chilibroste, P. (2003). Effect of the length and moment of the grazing session on milk production and composition of grazing dairy cows. *Tropical and Subtropical Agroecosystems*, *3*, 87–90.

Penn State University. (2017). From feed to milk: Understanding rumen function. Retrieved June 20, 2017 from http://extension.psu.edu/animals/dairy/nutrition/nutrition-and-feeding/rumen-function/from-feed-to-milk-understanding-rumen-function/extension_publication_file

Provenza, F. D. (1995). Postingestive feedback as an elementary determinant of food preference and intake in ruminants. *Journal of Range Management*, *48*(1), 2–17. doi:10.2307/4002498

Abbas Ahmadi is a computer scientist and software engineer for the last 30+ years at the Department of Animal Science, University of California Davis, USA. He is also an adjunct professor of computer science for the last 20+ years at the Cosumness River College, Sacramento, CA, USA. He has a BS degree in Biology (1968) from Faculty of Sciences (University of Tehran, Iran) and a MS degree in Public Health (1977) from College of Public Health (University of Tehran, Iran). He also has a MS degree in Computer Science (1986) from College of Electrical Engineering (University of California Davis, USA) and a PhD degree in Entomology (1986) from College of Agriculture (University of California Davis, USA). His research interest is focused on the application of computers in animal production systems.

Peter Robinson is a Cooperative Extension Specialist in Dairy Nutrition and Management at the Department of Animal Science, University of California Davis, USA. He has a BS degree from University of Manitoba (Winnipeg, Canada 1970-1974), a MS degree from University of Guelph (Guelph, Canada, 1974-1976), and a Ph.D. degree from Cornell University (Ithaca, NY, USA, 1979-1983). His research interests are focused on protein and amino acid nutrition of dairy cows, evaluation of methods to assess forage quality, management strategies to reduce the environmental impact of dairy cows, and animal metabolic models as tools to understand animal biology.

Pablo Chilibroste is a full professor of dairy nutrition at Department Animal Production and Pastures, Faculty of Agronomy, University of the Republic, Uruguay. He has a BS degree in Agricultural Engineering (1980 - 1985) from Faculty of Agronomy, University of the Republic, Uruguay, a MS degree in Animal Production (1992 - 1993) from Pontifical Catholic University of Chile, Chile, and a PhD degree in Animal Science (1995 – 1999) from Wageningen University & Research Center, The Netherlands. His research interests are focused on ruminant nutrition and simulation of animal production systems. Dr. Chilibroste is a world recognized expert on grazing systems of dairy cattle.

Francisco Elizondo is a Graduate Student (Master Program in Animal Sciences) at the Department of Animal Production and Pastures, Faculty of Agriculture, University of the Republic, Uruguay. He has a BS degree in Agricultural Engineering (1992 - 1999) from Faculty of Agronomy, University of the Republic, Uruguay.