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Update of an extant master plan for the development of a nutrient-based feed evaluation system that predicts dairy cow response to nutrition

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Abstract
Recent modelling efforts are discussed in view of the master plan for a nutrient based feed evaluation system for dairy cows. Digestive modules have been developed; more recently modules of post-absorptive nutrient (mainly amino acid) metabolism became available. The modelling efforts do not demand a basal change of the original master plan.

Keywords
Nutrient based feed evaluation
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1 Introduction

In 2000 a master plan was developed by Gerrits et al. (2000) describing the elements and set-up of a nutrient based feed evaluation system which includes dynamic, mechanistic models, and which describe the processes of nutrient conversions in various organs of the dairy cow and the cow's response to nutrition. For details of this master plan the reader is referred to the original report.

The aim of the present report is to give a summary of the developments since 2000 in dairy cow modelling and of new research results and insights that have become available from various research projects, and to indicate the consequences for the master plan for dairy cattle.

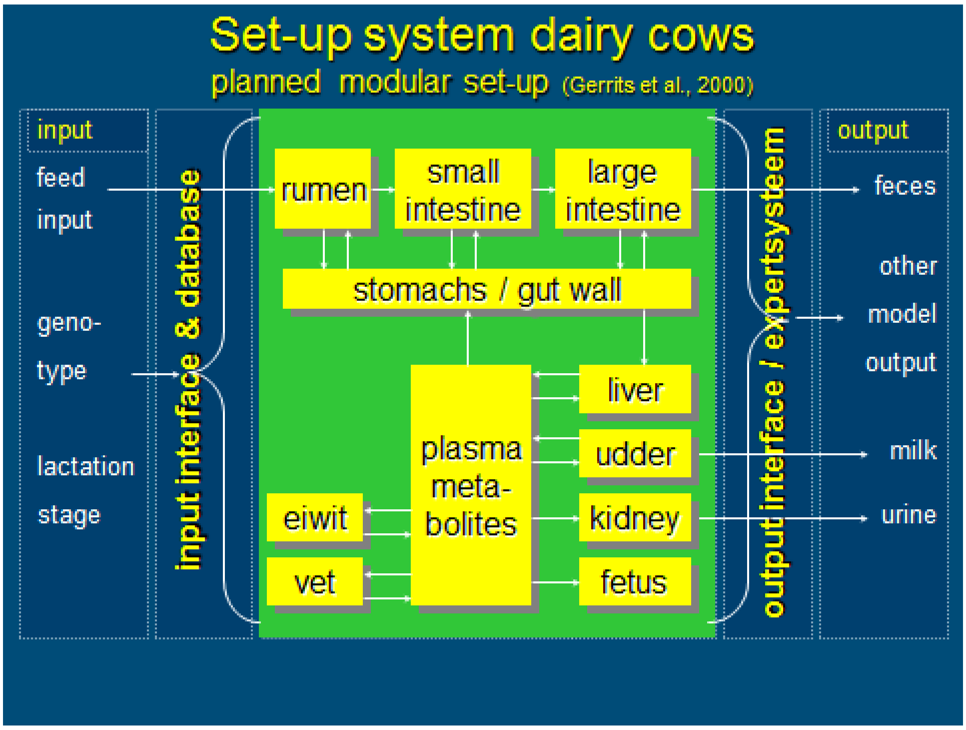

Figure 1 Conceptual framework of the nutrient based feed evaluation system for dairy cows (Gerrits et al., 2000)

The conceptual framework of the nutrient based feed evaluation system for dairy cows is given in Figure 1. On the input side of the system, the cow is defined by its genotype, stage of lactation (or physiological state) and parity. The diet is defined by ingredient composition and chemical composition of each ingredient in combination with the rumen degradation characteristics of the carbohydrate and protein fractions in these ingredients. Further inputs may be required for the prediction of rumen water volume, the fractional passage rate of fluid and particles, and particle comminution. Feed intake is not predicted but an input to the model and in this respect is not part of the predicted cow response. Reported methods of feed intake calculation (e.g. based on feed saturation values) may be used to obtain estimates of feed intake and add to the model. It is also foreseen that cow characteristics can be given as an input to the model such as the capacity for milk yield based on cow genotype, stage of lactation (or physiological state) and cow parity. On the output side of the system, predictions are given of the cow's response including milk yield and milk composition, body mass and composition, excreta composition and volume (including C, N and P), and emission of methane as enteric source of greenhouse gas. Also 'intermediate' results that are related to digestive (rumen, small intestine, large intestine), post-absorptive and productive organs will be available as predicted cow response.

2 Developments and research since master plan 2000

2.1 Introduction

Since the presentation of the master plan for dairy cows (Gerrits et al., 2000) several modelling projects have been conducted. Elements of the master plan have been carried out, or new aspects were modelled that were not yet considered in the master plan. These new modelling efforts will be discussed here, meanwhile indicating whether these necessitate a change in original set-up of the master plan and indicating what their importance is for predicting cow performance. Although these new modelling efforts mainly includes work of scientists of the Animal Nutrition groups of Wageningen UR (Centre of Animal Nutrition), the long-term collaboration with several international modelling groups has to be acknowledged; in the United Kingdom (Reading University), in Canada (University of Guelph; Centre for Nutrition Modelling) and in the United States (University of California, Davis) is acknowledged. Although many modelling efforts are conducted internationally and have been reported in literature, examples of renewed efforts in the area of dynamic, mechanistic modelling to include a representation of the underlying physiological mechanisms in dairy cows remain sparse.

2.2 Developments modelling digestive function in dairy cows, state of the art

2.2.1 Modelling digestive function: rumen

Since 2000, the rumen model as described by Dijkstra et al. (1992) and Neal et al. (1992) was improved on several aspects.

First, the model was adapted to describe the consequences of diurnal dynamics in feed intake (feed intake pattern, separating different meals, synchronisation of energy and protein intake) and particle comminution on rumen fermentation. Also, the effects of diet composition on rumen water volume were represented. This version of the rumen model was challenged with a variety in meal and feed intake patterns as an input, which showed to have a large effect on rumen pool sizes, but only limited effects on predicted rumen function. These findings correspond with observations reported in literature (e.g. the lack of a strong effect of synchronizing energy and protein on rumen function) (Bannink & Dijkstra, 2007).

Second, a model was constructed which allows the representation of multiple factors affecting rumen acid-base chemistry (Bannink & Dijkstra, 2006). The modelling effort demonstrated the importance of cation content of feeds and saliva production as causal factors in rumen buffering, next to that of volatile fatty acid clearance by absorption and fluid passage, which were represented already in the original model (Dijkstra et al., 1992). Some of the additional factors are hard to quantify for a given diet however, which hampers practicality to include this pH module in the rumen model. The module in itself is highly useful in predicting principle mechanisms of acid-base chemistry in various compartments of the gastrointestinal tract, and could also prove to be valuable for the modelling of digestive processes in monogastric animals. The module allows the quantification of the integral effect of various factors (e.g. dietary ions/salts or organic acids) that simultaneously affect acidity, and of this integral effect on digestive and fermentative processes.

Third, an updated stoichiometry was derived for the production of volatile fatty acids (acetate, propionate, butyrate, and other, mainly branched-chain, volatile fatty acids) from sugars, starch, hemi-cellulose, cellulose or protein fermented by micro-organisms according to the concepts used previously by Murphy et al., (1982). In contrast to existing publications, only rumen digestion data from lactating Holstein-Friesian cows as the target animal were used (Bannink et al., 2006). In a follow-up, the nonlinear regression procedure was adapted to take into account as well the effects of rumen pH, fractional acid absorption rate, fractional fluid passage and rumen volume. This led to a new set of coefficients which was rather similar compared to the original set derived by Bannink et al. (2006) at average pH, but which contained pH-dependent coefficients values for sugar and starch fermentation into VFA (Bannink & Dijkstra 2005; Bannink et al., 2008) for either roughage-rich or concentrate-rich diets.

Fourth, Dijkstra et al. (2000) developed a representation of the effect of fat and long-chain fatty acids on rumen microbial activity. This component of rumen fat metabolism only distinguishes saturated and non-saturated as classes of long-chain fatty acids, and the effect these exert on fibrolytic and protozoal activity and on whole rumen function. At a later stage, the representation of fat hydrogenation and fatty acid saturation was made pH dependent based on insights and in vivo observations reported in literature (Bannink et al., 2007). The representation of fat dynamics in the rumen is in general not of large importance to practice, but may gain importance when fat is used to improve milk fat quality, and to understand and predict methane production based on milk fatty acid profile.

Fifth, a representation of hydrogen balance and methanogenesis was added to the rumen model by Mills et al. (2001). In combination with the updated stoichiometry of volatile fatty acid production by Bannink et al. (2005; 2008), this version of the model includes a prediction of methane emission which is used as an IPCC Tier 3 approach for the Dutch inventory of enteric methane emission in dairy cows since 2005 (Bannink, 2011, Bannink et al., 2011). In contrast to the IPCC Tier 2 approach with a constant fraction of ingested gross energy assumed to become converted into methane energy, the Tier 3 approach actually predicts this fraction as a model outcome and allows to distinguish between the effects of feed intake, effects of diet composition and effects of rumen fermentation conditions on methane emission. The ability to predict as a function of the latter two aspects is of particular benefit when aiming to obtain realistic predictions for various nutritional options and when comparing diets. For example, Bannink et al. (2011) show with the Dutch Tier 3 approach a less steep increase in methane yield with increase in feed intake and milk yield since 1990, but a gradual decline in the fraction of ingested gross energy that becomes converted into methane energy from 1990 onwards. The IPCC Tier 2 approach adopts the default assumption of a constant 6.0% of gross energy intake (recently updated to a constant 6.5%) being emitted as methane.

Sixth, a representation was developed of the impact of adaptive processes in the rumen wall on acid absorption by rumen wall epithelia (Bannink et al., 2008, 2012). Although the representation remains rather conceptual and is difficult to parameterize because of a lack of useful in vivo data, it does represent trends recently observed in in vivo trials with a repeated measurement design, following changes in time within animal (Bannink et al., 2008). The models also allows to study the potential rate and extent of rumen adaptation which is of main importance in obtaining insight in the limits to adaptive capacity in dairy cows in early lactation (Bannink et al., 2012).

Seventh, Mills et al. (2014) integrated a module of lactic acid metabolism in the rumen model in order to obtain an improved prediction and understanding of the effect of nutrition on the risk on (acute) rumen acidosis. In this model version an alternative, more detailed representation of protozoal metabolism in the rumen was used, developed by Dijkstra (1994). The lactic acid module inserted in this version of the rumen model aims at describing the activity of micro-organisms producing and utilizing lactic acid, and includes a distinction between lactic acid producing bacteria and lactic acid utilizing bacteria, as well as competition between bacteria and protozoa for lactic acid utilization. Increase in lactic acid concentration after a meal was predicted reasonably for diets rich in non-structural carbohydrates. Although the lactic acid module could be a basis to extend feed evaluation with regard to risk on lactic acid accumulation, some aspects need to be improved still. For example, the model was unable to predict the effect of defaunation. It was also concluded that a more precise prediction of rumen pH is critical for prediction of lactic acid accumulation. In this respect, the above mentioned module of acid-base chemistry could prove very useful, or empirical relationships to predict rumen pH should be improved.

2.2.2 Modelling digestive function: small intestine

A dynamic, mechanistic model has been constructed describing the digestion of starch, fat and protein in three subsequent compartments of the small intestine; the duodenum, the jejunum and the ileum. The models represent the secretion of enzymes in response to nutritional factors and passage of digesta through the small intestine. A representation of microbial activity in the small intestine was not included as it was assumed not to contribute substantially to digestion. Easily and rapidly fermentable substrates will have been fermented already in the rumen, which makes the case for dairy cattle very different from that for monogastric animals. The models could be evaluated to a limited extent. Evaluation results indicate in a qualitative manner how various nutritional aspect affect intestinal digestibility and model response seems to give a better match with observed responses in ileal digestion in cattle reported in literature (Bannink et al., 2009). The modelling results indicate that digestibility of starch, fat and protein is variable and it may hence serve to determine how digestion coefficients in the small intestinal vary with feeding conditions, replacing the adoption in current feed evaluation systems of rather constant values for digestibility coefficients. Further model development and testing is needed however, as well as more precise parameterization of some basal processes that are strong determinants of predicted intestinal digestibility but for which in vivo data in lactating cows are scarce.

2.2.3 Modelling digestive function: large intestine

A dynamic, mechanistic model which is comparable to that for the rumen was developed for the large intestine by Mills et al. (2001). The model has its own specific parameterization for volume, fractional passage rate of digesta and microbiota, and of pH parameters. The same stoichiometry was assumed for volatile fatty acid production as represented in the rumen model according to Bannink et al. (2006). Bannink et al. (2011) introduced an updated stoichiometry of volatile fatty acid production which was made pH dependent for sugar and starch fermentation (Bannink et al. 2005, 2008). Furthermore, the fractional passage rate was made dependent on the accumulation of volatile fatty acids in the large intestine compartment. In effect, this causes an increased fractional passage rate, and hence lower retention time of micro-organisms and substrate with increased rates of fermentation. Model predictions indicated that a strong increase in fermentation rate results in a substantial decline in predicted population size of fibrolytic bacteria and fibre degradation. With further increase of fermentation rate it is even predicted that fibrolytic micro-organisms become extinct and digestion of fibre is even totally absent. Such simulation results demonstrate the importance of the prediction of starch outflow from the small intestine into the large intestine and the impact of presence of rapidly fermentable substrate in the large intestine on fibre digestion. The concept seems to match sparse indications from in vivo data reported in literature.

2.2.4 Integration of digestive function models

The individual models developed for feed digestion in the rumen, small intestine and large intestine can be combined and present digestion in the full gastro-intestinal tract of a dairy cow. Given feed intake, ingredient composition of the feed and ingredient characteristics (chemical composition and in situ degradation characteristics) as an input to such an integrated digestive model, the site of fermentation, of digestion and of absorption of nutrients can be predicted, including the production of methane. The model also predicts the faecal composition, since the most important elements that contribute to urine and faeces composition are represented with the mechanistic approach. Thus, the integral model is able to predict the amount and type of organic matter excreted in faeces, including its C, P and N content and its constituents. The latter predictions are relevant for understanding the effect of excreta on losses after excretion (from stall floors, during storage or after manure application to soil) largely depend on amount and composition of excreta. For example, the decomposition of fibre-rich residues in soil is much slower, than that of undigested microbial OM. Similarly, the type of N excreted determines its rate of volatilization as ammonia (Reijs, 2007; Dijkstra et al., 2010).
Some additional aspects of rumen function have been modelled meanwhile (e.g. rumen lactic acid metabolism, rumen fat metabolism) which may or may not be used, without consequences for realization of the master plan originally proposed.

With the finalisation of the dynamic, mechanistic models of the rumen, small intestine and large intestine, the digestive part of the modules proposed in the master plan In Figure 1 has been realized.

2.3 Modelling post-absorptive metabolism: state of the art

In the EU-program REDNEX (*REDucing Nitrogen EXcretion*) nutrient metabolism in organs was modelled which is of major importance for nitrogen metabolism. Dynamic, mechanistic models were developed for the gut wall, the liver and the mammary gland with main emphasis on the representation of amino acid metabolism. The newly developed models were demonstrably more robust and accurate than modelling exercises already reported in literature. All models were constructed in such a way that they can be linked to the digestive modules discussed in 2.2. A fully integrated version of the EU-REDNEX models is described in 2.3.1 to 2.3.4 and showed satisfactory predictions of milk production and nitrogen excretion within the bounds the model was tested for (12 to 30 kg DM/d). This means that the combination of these models serves as a basis for an integrated post-absorptive model that can replace current empirical equations with milk composition given as an input to derive nutrient utilization for milk production.

2.3.1 EU-REDNEX amino acid metabolism gut wall

A model was constructed that describes the variation in the extent of amino acid oxidation in tissues of the gut wall, including a diversification of the extent of oxidation among individual amino acids. The model explains the implications of amino acid composition of the feed, microbial matter and endogenous sources on amino acid oxidation by the gut wall tissues. The model predicts this response to rumen bypass feed protein and the amount of microbial protein synthesized in the rumen, flowing to the intestine.
At present, rumen wall tissue metabolism has not been addressed separately from gut wall tissues. Making such a distinction remains future work to improve predictions of net amino acid oxidation by visceral tissues. Besides aspects on tissue metabolism, also the representation of tissue mass requires further attention in order to use the model within a whole cow setting (as described in the master plan; Figure 1).

2.3.2 EU-REDNEX amino acid metabolism liver

A further model was constructed that describes the amino acid metabolism by liver tissues. Energy metabolism was simplified from a previously developed, detailed model such that the model continued to show good performance for inputs related to extreme diets very high or very low in protein content, or in energy content. The model response is sensitive to both nitrogenous and energy inputs, and also interactions between nitrogen and energy metabolism were according to observations reported in literature. The concepts adopted in the model and the adaptations that were made relative to the models reported in literature demonstrated a substantial improvement in predictive performance in terms of accuracy and robustness.
Further work is needed on the representation of liver size and the effects of genetic potential and stage of lactation on liver metabolism. Inclusion of these aspects is necessary to let the model perform satisfactorily within a whole cow setting, including effects of parity and lactation stage.

2.3.3 EU-REDNEX amino acid metabolism mammary gland

A third model was constructed for nutrient metabolism in the mammary gland of dairy cows, with emphasis on the metabolism of amino acids and the process of milk synthesis. Challenge of the model on an independent database revealed that the model predicts milk yield and yield of milk protein, lactose and fat adequately, but improvements to the model are necessary to accomplish a further improvement of prediction accuracy.
Advancements that need to be made include a representation of mammary size and genetic potential for milk production. The latter seems prerequisite for having the model perform within a whole cow setting. Improvements are also needed with respect to milk lactose prediction (a major driver of total milk yield), and with respect to the current prediction of an inadequate amino acid delivery to the mammary gland given a known milk protein output which necessitated the introduction of an ‘unidentified’ amino acid source as correction factor.

2.3.4 EU-REDNEX urea recycling to visceral tissues and rumen

Experimental and modelling work demonstrated that dairy cows only can to a very limited extent, or not at all, compensate for a reduced rumen degradable protein intake by a concomitant increase in urea recycling. For this reason there is little scope to represent urea recycling at various crude protein levels in a far more detailed level than the current representation in the dynamic, mechanistic model of the rumen (Dijkstra et al., 1992). This representation, with a stimulatory effect of blood urea concentration (indirectly, via dietary N intake) and an inhibitory effect of rumen ammonia concentration on urea recycling to the rumen, corresponds best with recent in vivo observations in lactating cows,

and seems functionally more adequate than representations chosen in other modelling exercises reported in literature.
No further changes are proposed for the representation of urea recycling.

2.4 Quantifying milk urea as an indicator

Spek et al. (2012a; 2012b; 2013a; 2013b; 2013c) studied the background of variation in the milk urea content that is unrelated to the daily amount of urea excretion in urine, or with urine and faeces. Various dietary, animal, and farm factors were identified to affect milk urea content. Equations were derived for the effects of crude protein content of the diet and urine volume. In addition to these rather static factors, also more dynamic factors can influence milk urea content. Diurnal variation in digestive processes and nitrogen absorption (ammonia and amino acids) next to diurnal variation in the process of milk synthesis, may affect the milk urea content in collected milk. Therefore, the representation of feeding frequency, feed intake pattern and the distinction between different meal types (e.g. as a result of grazing management) and of milking frequency become important as well.
Static equations have been developed to represent some import factors. Future work aims at the development of a dynamic, mechanistic model including a representation of the dynamics in blood and milk urea content as function of dynamics of feed intake and digestion , of water intake, and of milking. These modelling efforts have no further consequence for execution of the master plan, and the milk urea module can relatively easily be combined with the models / modules already developed and discussed in previous sections (Figure 1).

2.5 Quantifying phosphorus

2.5.1 Meta-analyses

Two quantitative studies have been performed recently on phosphorus (P) metabolism and excretion in dairy cows by Klop et al. (2013a; 2014). A first analysis indicated a clear relationship between milk constituents lactose and protein on the one hand and milk P content on the other hand. A relationship was derived that provides a much better estimation of milk P content than the adoption of a fixed factors between 0.9 and 1.0 g P/kg milk in current systems for P requirements of dairy cows. A considerable fraction of observed variation in milk P content remained unexplained, which deserves further research to explain. A second study analysed data from P balance trials and delivered equations to predict faecal P as a fraction of P intake or to predict milk P content, which could not adequately explain the observed variation and did not perform well. This could to a large extent be attributed to the confounding effect of cow P balance.
The relationships from both studies are useful to guide the further development of dynamic, mechanistic models on P metabolism in dairy cows and to identify which aspects require an improved representation. Factors to consider in future experimental research and in modelling exercises include the effects of dietary neutral detergent fibre, crude protein and starch, variation in milk P content, and the effects of the regulatory mechanism involved with P mobilisation from bone and body tissues around parturition.

2.5.2 Dynamic, mechanistic P modelling

A dynamic, mechanistic model of P metabolism in dairy cows has already been published by Hill et al. (2008). This model is planned to be used as a starting point for further P modelling work. The model represents digestive aspects of P in considerable detail, including the effect of phytase and amounts of feed phytate, intestinal passage rate, an intestinal absorptive capacity. However, a rather static parameterization was adopted for the post-absorptive aspects of P metabolism as identified by Klop et al. (2013a; 2014) and in a preceding review by Bannink et al. (2010b). A more dynamic representation of these post-absorptive aspects is imperative for a realistic representation of variation in P metabolism in dairy cows around parturition, including Ca metabolism and feeding and requirements of calcium.
Further modelling work on P metabolism probably will focus on the representation of the dynamics of calcium metabolism, bone metabolism, P recycling with saliva (a highly active and hence regulated process) and regulation of P excretion with milk. Furthermore, attention is needed for the

representation of the consequences on P excretion with faeces to identify how faecal P reflects the P status of a lactating dairy cow in various stages of lactation (normally, excretion of P with urine negligible).

2.6 Summarizing

Digestive modules were developed in past decades on digestive and post-absorptive functions. At the moment the digestive modules seem rather complete. Continuing modelling efforts are needed on representing the effect on post-absorptive functions. These need to become represented in a less static manner and in more detail, and need to replace current concepts in protein and energy requirement systems used in practice. Recently, several models were delivered and evaluated against independent in vivo data that serve as a base for the post-absorptive modules described in the master plan. They all need further development however. Also modules have to be included for body reserves of the dairy cow and the foetal growth.

In addition to aspects described in the original master plan, there is scope for adding a description of the dynamics of P metabolism, P excretion and P status of the cow, including calcium metabolism (of main importance during the transition period, and because of the relationships between of P and calcium metabolism). Milk urea may be used as a proxy for nitrogen excretion (and protein nutrition), but this requires a representation of the consequences of nutrition on blood urea dynamics which are non-related to nitrogen excretion. Improvements are still needed in the lactic acid module before it can be used as a reliable predictor of rumen acidosis that is related to accumulation of lactic acid under intensive feeding regimes.

3 Further model development

With respect to the accomplishment of the fully integrated nutrition based feed evaluation system as described in the master plan (Figure 1; Gerrits et al., 2000) several further modelling efforts are needed. There appear no crucial aspects of rumen function that remained non-addressed with previous modelling efforts. In view of rapid developments of additives to reduce methane emissions, the model does still lack a dynamic, mechanistic representation of certain methane inhibitors. For example the large and persistent reducing effect of nitrate on methane production (experimentally shown by Van Zijderveld et al., 2010, 2011) could be modelled rather easily. More uncertainty exists with other additives with less persistent effects. Also, an improved parameterization is needed of the models of digestive functions in the small intestine and of large intestine. Further in vivo research is necessary, next to modelling work, identifying processes and parameters under various feeding conditions. Further development is needed as well of the models of the gut wall, the liver and the mammary gland to make them fully nutrient based, and to include a representation of variation and dynamics in organ mass and effects of cow genotype. A representation of the effects of lactation stage on the activity of key organs, which includes gut wall, liver and mammary gland, need to be developed. Finally, development is needed of dynamic, mechanistic models or of empirical equations (linking up to existing modules) for foetal growth, body protein and energy reserves (fat tissue).

4 Implications for dairy cow master plan

In recent years, the digestive modules included in the master plan for a nutrient based system to predict the response of a dairy cow to nutrition have been developed and extended for the rumen, small intestine and large intestine. Furthermore, the recently developed modules of post-absorptive amino acid metabolism may well serve as a basis for the dynamic, mechanistic modules proposed in the master plan for intermediary metabolism and milk synthesis (Figure 1).The post-absorptive modules still require extension and further modelling efforts, however, to realize a fully integrated representation of nutrient metabolism including all relevant nutrients .

Although not part of the master plan, some additional aspects can be introduced in some of the modules. Specific modules need to be developed for each of these aspects, which may be dynamic, mechanistic models in themselves, but this will have no serious implications for the development of the modules described in the master plan.

5 Phasing of the project

For the further model development to finalize the master plan for dairy cows different phases are distinguished. They are outlined in Table 1. As a result of the research budget available in 2014, a start will be made with addressing P and milk urea as added aspects. Next, further modelling of the post-absorptive metabolism and productive organs is foreseen.

Table 1 Proposed phases of the project

Phases	Focus	Aspects
Phase 1	Development a dynamic, mechanistic model of P metabolism in dairy cows, including an examination of the value of potential indicators of the P status of cows	Focus on post-absorptive aspects of P metabolism (milk, bone, recycling), instead of digestive aspects which are far more a response on post-absorptive P metabolism and P–status than with mono-gastric animals.
	Development and linkage of a quantitative model representing effects of influencing factors on milk urea.	Feed factors, animal factors, farm factors; including representation of the consequence of diurnal blood urea dynamics on milk urea.
Phase 2	Further development of dynamic, mechanistic models of nutrient metabolism and functioning of visceral tissues, liver and udder; develop simplified models for organs/tissues not included in these 3 models.	Develop fully integrated model which does not focus on amino acid metabolism only, but includes other (non-amino genic) nutrients in more detail than current models.
	Adaptation and update of the user interface that is currently under construction for the Tier 3 approach to predict enteric methane in dairy cows	User-interface needs to be able to handle and deliver insight up to organ level about the fully integrated model.

6 Available data

Dynamic mechanistic models already have been developed for the digestive functions of the cow rumen, small intestine, and large intestine, including the representation of microbial activity. Also, models have been developed to represent amino acid metabolism in visceral tissues, liver and udder, with a so-far more simplified representation of energy metabolism. All models have been evaluated against independent data to some extent, and model behaviour was studied for consistency and logicality in model response by a comparison with insights in literature. Sensitivity of model response to parameter values has been tested which identified parameters that have a key role for obtaining accurate predictions. The models help in making a precise formulation of the type of knowledge needed from experimental work, and importantly. In this way areas can be identified which require further research and hence the modelling exercises aid in focussing and prioritizing experimental research.

Ongoing international research can be used continuously to further evaluate and improve the models developed and discussed in Chapter 2. Most relevant outcomes from literature can be inspected and compared with model responses. Existing contacts and networks in the international scientific community on modelling of cow response in terms of digestion and metabolism of nutrients can be used to further evaluate and improve the models.

In the Topsector Agri & Food programme Feed4Foodure (F4F) various projects started on three sub-themes: ‘More with Less’, ‘Social Responsible Livestock Farming’ and ‘Diet, Intestinal Health and Immunity’. However, the experimental work is largely directed at monogastrics. Some valuable data for dairy cows become available from the F4F projects ‘Reducing energy losses’ and ‘Reducing phosphorus losses’ but these projects are not directed at the level of the individual modules defined in the master plan for pre- and post-absorptive nutrient metabolism. The project Low Emission Animal Feed (brought under the F4F project ‘ Reducing energy losses’, running from 2011 till 2016) actually does foresee in a close exchange between modelling and experimental work, in order to fine-tune both (Bannink & Dijkstra, 2011), but his project aims at methane emission instead of nutrient metabolism.

Data to challenge and parameterize the models for diverse nutritional conditions and cow performances are scarce. In particular data on nutrient flows from the intestine and nutrient flows between organs involved in intermediary metabolism (gut wall, liver and mammary gland) and productive functions are scarce. Although a gross simplification of the variation encountered, it is expected that the dairy cattle sector will reduce the input of high-quality, human-edible feed (such as grain and soybean meal), will be characterised by lower protein diets (not above some 14% crude protein) and low P diets (not above some 3.5 g P/kg DM), possibly including alternative (fibrous) products and roughages with changed dietary qualities as a result of manure legislation and farming practices.

7 Model evaluation

For an application of the models developed it is imperative to know the accuracy and precision of model prediction of processes related to digestion, growth, body reserves, productive responses (milk, foetus), excretion and methane emission. Apart from testing of accuracy and precision of the model by comparing predictions against independent observations, also an evaluation is needed of the nature of the model response to variation in model inputs (behavioural analysis) and an analysis of the impact of model assumptions on predictions (sensitivity analysis). Most of the modelling work since 2000 discussed in paragraph 2.2 ‘Developments and research since master plan 2000’ included both types of model evaluation. Further evaluation studies are welcomed however.

8 Implementation of the system by introduction of a user interface

During an orientation phase with potential users from advisory boards and from animal feed industry, the specifications of the user-interface were identified and documented (Bannink & Gerrits, 2004a; 2004b). At the moment, as part of the ongoing research program Low Emission Animal Feed, a user-interface is developed for the Dutch Tier 3 model which predicts enteric methane emission in dairy cows. Input and output screens have been developed in full detail with functionality of the tools described. A core group of representatives from the sector is guiding the development process and is used for feedback and reflection of user-friendliness. They will be the test panel for the first beta version of the interface which is foreseen to become available in spring 2014.
New modelling efforts and developments can be added to this interface. As long as the coding of the model inputs and model outputs of renewed versions of the models remain unaltered this can simply be achieved by replacing the encoded version of previous model version in the form of a DLL (which runs stand-alone without need for simulation modelling software as an environment) by the DLL of the renewed version. If input - output coding of a renewed model do change, additional work by ICT-experts is needed to adapt the user-interface as well. Adding details without changing the basal set-up of existing modules will likely require least efforts. If there are serious basal changes in the underlying structure of individual modules and in the communication between individual modules, with data-bases, with data management or with required calculations based on model outcomes, efforts will be substantial.

9 Conclusions

Parts of the master plan reported in 2000 for the development of a nutrient based feed evaluation system for dairy cows has been executed since. Modules for the digestive tract have been developed. Modules for post-absorptive nutrient metabolism have recently been developed as well, although they require further development for a full integral handling of all nutrients and of the physiological status of organs, to be let them function properly within a whole cow setting. Although some further aspects have been modelled meanwhile and may be included in certain modules included in the master plan, the original plan of 2000 basically remains unaltered.

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