Modelling Applications to Pasture-Based Beef Production in Atlantic Canada

By

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DEDICATION

To my parents, Debbie and Lewis Benedict

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ABSTRACT

A system model of a pasture-related beef production, entitled the Atlantic Pasture Based Beef Model (APBM), was developed and evaluated for Atlantic Canada. The model was used to examine the effects of calving season (winter or spring) and pasture type (naturalized or improved) on the animal output in calf gain (kg). The model was coded in Stella 5.1 High Performance Systems modelling software using previously published models to represent the two main components of the system: plant and animal. The plant component, a timothy (*Phelum pratense*) production model, simulates, on a daily time step, metabolizable energy (ME), crude protein, and biomass accumulation from environmental inputs. The animal component utilizes the ME output of the plant to satisfy energy requirements for maintenance, growth, and production. Finally, the environmental inputs were generated by a weather component that was based on the Canada Climate Normals for Truro, Nova Scotia. The individual component models and the system model were evaluated through verification, calibration, and validation using data collected from beef research and farm systems in Atlantic Canada. The calibration of the plant component was completed using the data from years of research trials at Nappan, Fredericton, Charlottetown, and Truro. The animal component was calibrated based on the chosen breed of cattle (Hereford or Hereford cross). The validation results, in terms of the coefficient of determination (r^2), indicated that the system model and components represented the collected data with a reasonable degree of accuracy. The plant component represented improved forage grass species fairly well (r^2 value range: 0.61-0.96) with the most accurate estimations for tall growing grass species similar to timothy. Naturalized species were not represented as accurately (r^2 value range: 0.16-0.49) and forage legume species tested in this research were poorly represented by the model (r^2 value range: 0.04-0.11). The individual animal component represented the data moderately well (r^2 value range: 0.54- 0.65). The design of this system did not account for the effect of grazing on plant quality or production. When the system was assembled, the accuracy of the model's prediction for the plant ME remained the same and the accuracy of animal gain prediction increased slightly (r^2 value range: 0.57-0.80). The degree of accuracy for prediction from this model and its components was consistent with models tested in the past. In general, these results indicate that there may be a need to develop forage quality models that are more species specific and account for multiple species competition in regards to plant growth and quality. Also, increased accuracy of prediction may be needed for the animal production component as well.

List of Abbreviations

APBM	Atlantic Pasture -based Beef Model
kg	Kilogram
ME	Metabolizable Energy
NRC	National Research Council
CNCPS	Cornell Net Carbohydrate and Protein System
HPS	High Performance Systems
ha	Hectare
CCN	Canadian Climate Normals
MJ	Mega Joules
Mcal	Mega Calories
DMI	Dry Matter Intake
NE	Net Energy
NE_m	Net Energy required for maintenance
NE_g	Net Energy required for gain
SRW	Standard Reference Weight

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Introduction

In Atlantic Canada, forage is a local feed resource that is readily available for beef production. This region, compared with other areas of Canada, has distinct conditions that combine to make it well suited for the production of forages namely: the low cost and availability of land, the mild climate and the well-distributed rainfall (Butler et al. 1993). The Atlantic beef production system should aim to take advantage of its forage growing capabilities. Pastures are another resource that should be used in the development of profitable beef systems. Nicholson et al. (1983) conclude that pastures are the most economical source of feed for a cow-calf operation in Atlantic Canada.

In 1977, an Economics Branch of Agriculture Canada document (Economics Division, 1977) recommended that winter calving, under the current operating conditions, was the most profitable beef production system for Atlantic Canada. This recommendation was based on a three year (1971-1974) experiment. At that time, cows calving in winter (January-February) weaned significantly heavier calves than cows calving in the spring (April 12-June 15), which in turn translated into more profit.

The output and input costs of beef production have changed over the past 20 years, and so there is a need to reexamine the previous recommendations for beef production in Atlantic Canada. Currently, in 1999, input costs have increased and the prices of outputs appear to be less stable. Alternative management practices, which can make better use of available resources, need to be investigated.

Evaluating all possible systems for beef production would be an enormous task using traditional experimental procedures. Thus, in this study, we chose to use computer modelling as an effective tool to utilize previous experimental results and assembled models that predict the behaviour of newly proposed production systems. This investigation was initiated to utilize computer simulation models in an attempt to evaluate various beef production systems.

The key objectives for this investigation were:

1) To establish a feed energy model of an Atlantic Canadian beef production system using previously developed models and data that optimize pasture utilization and can be used to predict costs.

2a) To conduct a sensitivity analysis for the established model.

2b) To conduct verification, calibration and validation analyses comparing the model's predicted values to observed values.

3) To use this model to investigate the following hypothesis: Optimal pasture utilization that relates to pasture type (improved, naturalized) and calving time (winter, spring) will have a positive influence on the profitability of beef production in Atlantic Canada.

Chapter 1:

Literature Review of Beef Animal and Pasture/Plant Production Models

1.1 Introduction

There is a demand from policy makers, and other interested parties, for system modellers to assess the broader and long-term effects of different management applications on biological systems (Gaunt et al. 1997). In agricultural modelling, many different types of models have been developed for fragments of agriculture production systems. Physiological and nutrition models are available for many different crops and species of animals. Few agriculture systems models, however, have been developed for pasture related beef production and almost none have been evaluated for the Atlantic region of Canada (Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland).

1.2 Beef and Pasture Related Models

1.2.1 Introduction

Modelling of agricultural production systems is based on a large number of complex interactions among entities within the system. Computer software can assemble this large and complex body of knowledge; it can predict the outcome or the behaviour of the system under hypothetical policy and management changes which would be too expensive to research (Cohen et al.1995). Agricultural research has traditionally focussed on experimentation of farm system components, such as crop growth. With computers, the results of different component experiments can be consolidated into a representative system.

Simulation modelling in agriculture can be expected to: 1) enable preliminary assessment of how new conditions or new techniques affect the system response and, 2) provide a means to explore system behaviour (Seligman, 1993). For example, if the stocking rate of cattle on a paddock is increased, the researcher can assess its effect on other parts of the system, such as pasture growth.

1.2.2 Beef Animal Related Models

Animal science and animal production modelling is based on the interactions between environmental, digestive, physiological, and metabolic elements that determine animal performance (Baldwin, 1976). Animal models in the past have ranged from simple mathematical equations, as predictors of animal performance, to complex dynamic simulations of whole animal production systems (Table 1).

In 1968, Lofgreen and Garrett devised a system to predict the net energy (NE) requirements and feed values for growing and finishing beef cattle. This study used meat production of the cattle and slaughter weights to predict the net energy requirements for growing and finishing beef cattle. This empirical approach gave the predictive equations for a specific breed of cattle under given experimental conditions. Webster et al. (1977) used a similar, narrowly based empirical approach. Experimental data on intensively reared cattle were used to develop a predictive equation for the use of metabolizable energy (ME) by beef cattle. Unfortunately, the empirical nature of these two models limits their use outside the given experimental conditions.

Cartwright and Sanders, (1979) developed a deterministic beef production model based on a Texan production system. This model takes into account cattle genotype, breeding season, and environmental conditions. The model requires a feed resource input and the production stages of the animals. It was validated for several different equatorial regions

Table 1. An overview of beef and sheep production models.

Model Focus	Model Prediction Objective(s)	Reference
Beef cattle growth	Net energy requirements	Lofgreen and Garrett, 1968
Beef cattle growth	Energy requirements	Webster et al. 1977
Cattle growth	Based on feed intake	Cartwright and Sanders, 1979
Sheep	Rumen process and animal performance	France et al. 1982
Cattle	Growth and composition	Oltjen et al. 1986a
Sheep	Relating nutrient supply and carcass	France et al. 1987
Cattle	Maintenance requirements	Fox et al. 1988
Cattle	Nutrient requirements and animal production	Fox et al. 1992
Cattle	Feed intake and rumen function	Demment and Greenwood, 1988
Holstein steers	Feed intake and animal gain	Rayburn and Fox, 1990
Grazing cattle	Daily dry matter intake	Hyer et al. 1991a
Cattle	Biological and economical performance	Davis et al. 1994
Dairy cattle	Nitrogen flow	Duynisveld, 1996
Beef cattle	Nutrient requirements	NRC, 1996
Steers	Rates of gain	Hironaka et al. 1997
Sheep/cattle	Intake, production and reproduction	Freer et al. 1997
Beef cattle	Animal production	Naazie et al. 1997
Cattle	Full biological model	Loewer, 1998

The management application included: breeding season changes, crossbreeding programmes, and production efficiency trials. Although the authors state that the model performed well for the given validation trials, no quantified or statistical results were given to substantiate their claim or to indicate its level of effectiveness. This model is one of the main animal production models developed in the United States and has been used as the basis of further production models (Loewer, 1998).

France et al. (1982) developed a dynamic sheep model to study the effect of rumen process on animal nutrition and performance. The variables examined were: rumen metabolic volume, non rumen degradable hexose, rumen degradable hexose, water soluble carbohydrate, non protein nitrogen, rumen degradable protein, and non rumen degradable protein. Microbial growth and catabolism variables were also examined. The steady state variables, predicted by the model, did not compare well to experimental values; the author attributed the deviations to rounding errors in the model.

Five years later, France et al. (1987) developed a dynamic model to test whether changes in nutrient supply could alter carcass composition in beef cattle. The model was developed in terms of absorbed nutrients, mainly carbon, amino acid concentration, body ash, body lipid, and body protein. Simulations were made over several weeks, and it was found that the predicted values compared well with the experimental data. This model gave a simplified view of the biochemical representation of nutrient utilization for body growth. The validation of this model was limited to only three different feeding trials and subsequent slaughter, but the authors found that there was moderate agreement between predicted and actual values.

To examine the development of post-weaning beef cattle growth and carcass composition, Oltjen et al. (1986a) designed a dynamic model of protein accumulation. The model used energy intake, frame size, and mature body weight to estimated the body weight change and fat content of British breed steer. The model predicted body weight within 14 kg and the fat content within 10 kg. Energy intake differences between breeds and different environmental conditions were not taken into account. The validation of the model consisted of verification of model behaviour compared with the model previously developed by Cartwright and Sanders (1979) and with the National Research Council (NRC)(1984)model.

Fox et al., (1988) designed a model to adjust the maintenance requirements of cattle for various combinations of temperature, wind, hide, haircoat, activity, and present level of nutrition. The authors wanted to present a system that could be easily applied to a wide variety of feeding conditions, namely, to aid in balancing diets and to help in preparing feed and economic budgets.

The authors used animal frame size categories ranging from 1-9, smallest to largest, to estimate body composition and energy requirements per kg of gain during feeding. Adjustment factors used in this model were: time when yearling started to feed, breed of animal, percent fat, use of implant, feed additives, finely or coarse diet, temperature and wind.

The model was validated and a sensitivity analysis was performed. The validation was extensive and was completed for each section of the model. The model was most sensitive to diet and the amount of insulation the cow had. The model predicted requirements for lactation that were within 5% of the NRC (1985) values. Energy requirements for gain differed by 6-8% from the NRC (1985) values; under commercial feedlot conditions, this model predicted within 1-5% of the actual gain.

This model (Fox et al. 1988) was further tested by Rayburn and Fox, (1990). It was also refined to more accurately predict dry matter intake, average daily gain, and feed per gain for Holstein steers under different feeding systems and environments. The parameters used for testing the model were: animal body weights, dry matter intake, average daily gain, feed per gain, and diet concentration of metabolizable energy. Adjustments were made for body condition, implants, and feed additives. Model accuracy was tested, and it accounted for 93% of the variation in dry matter intake, 56% of the variation for average daily gain, and 68% of the variation in feed per gain. Animal descriptions of breed weight and age were the most sensitive for estimating dry matter intake, average daily gain, and feed per gain. Under colder temperatures, the model was sensitive to all factors associated with increased heat loss. Overall, the authors stated the precision of the predicted values for observed values were reasonable and within the context of the study.

The Cornell Net Carbohydrate and Protein System (CNCPS) developed by Fox et al. (1992) predicts nutrient requirements and animal performance for different cattle breeds, different feeding regimes, management, and environmental conditions. This model is also based on Fox et al.(1988), and modified to include an integration of different physiological and metabolic animal models. These models have both empirical and deterministic features.

The CNCPS model was validated using limited validation data and experimental data. The observed values were compared with NRC (1985) and output of other models.

The results indicated that the model provided predicted values closer to the observed values than NRC predictions. This model was also evaluated by Fox et al. (1998) and extended to include the length of growth periods for calves on high forage diets.

Demment and Greenwood (1988) developed a dynamic model to predict intake of cattle, specifically how it relates to body size, rumen function, and ingestive behaviour of animals grazing on pasture. Inputs were: bite size, chewing rate, rumination required, and grazing time and the parameters included body size, rumen function, energy costs, and forage composition. Outputs were: energy digested from cell solubles and cell wall, basal metabolic costs, costs of grazing, rumination, movement and length of time spent grazing. The model relies heavily on theoretical data and attempts to integrate behaviour, body size, and consumption of cattle into one model. There was little validation done, but the authors looked at trends of similar behaviours in field trials.

Hyer et al.(1991a) developed a mathematical model to predict the daily dry matter intake that accounts for effects of energy supplementation on forage intake by grazing cattle. The model was based on France et al. (1982) and consisted of differential equations, rate constants for nutrient use, microbial composition, and growth constants and coefficients relating dry matter intake to particulate passage rates. Forage intake was assumed to be limited by rumen fill. The authors found that roughage intake was sensitive to changes in particulate digesta flow, dietary content of undegraded fibre, and how quickly the slowly degraded dietary fractions broke down.

The model used the "scaling rule" to convert the original equations used for sheep to cattle proportions. It was evaluated using data from different pasture plant samples.

Hyer et al.(1991b) found that this mechanistic model could be used to predict intake that responded to changes in diet, however, intake did not respond to protein supplementation. This model might be useful to predict basic intake for forage diets, but not when supplements are being given.

Davis et al.(1994) developed a computer simulation model to compare biologically and economically different breed groups in a cow-calf range production. It was developed specifically for a data set collected over ten years. The breeds evaluated were: Angus, Hereford, Simmental, Simmental-Hereford (50-50%) and Simmental-Hereford (75-50%). Inputs were: cow weight, calf weight, pregnancy rate, dystocia, and calf survival. Performance outputs included survival of calves, milk production, and body weights.

NRC (1996) presented a model that was developed to predict the nutrient requirements of beef cattle at all stages of growth and production. Adjustments are made for breed, physiological state, activity, and heat loss. Growth, lactation, energy and protein reserves are all calculated, and predicted dry matter intake has multipliers to adjust for breed, fat implant, temperature, and mud. This model is based, with a little modification, on Fox et al. ,(1988). Animal weight gain was predicted with approximately 67% accuracy. The performance of several models have been measured against the NRC (1996) model.

Rate of gain predictions are compared by Hironaka et al. (1997). An empirical set of equations utilizing digestible energy (DE) as a predictor of gain was compared with the NRC (1984) NE of gain system. The comparison was done using data collected from

Hereford steers fed varying proportions of concentrate and silage ratios from 100:0 to 0:100, respectively. The DE system was a more accurate predictor of gain overall, but there was variation in rate of gain prediction with changes in diet composition.

GrazFeed (Freer et al. 1997) is the animal component of an Australian grazing-decision support system. This system was originally developed for sheep production and uses a scaling rule to simulate beef production. The assumption was that beef cattle would differ from sheep by a standard reference (body weight). It accounts for production stage of the animal breed, climate conditions, activity on pasture, and how they effect energy and protein use. The authors claim that the major difficulty with this system is ensuring that the user is providing accurate pasture statistics.

Efficiency of beef production in North America was modelled by Naaize et al. (1997). Efficiency was based on the amount of output in a meat equivalent value compared to feed input in terms of metabolizable energy. The model sought to evaluate the overall efficiency of cow-calf, dairy-beef, and beef production systems. This model was divided into three components: 1) growth and feed intake; 2) herd, and 3)efficiency. The animal growth component is the sole dynamic section of the model, and uses an exponential equation to estimate growth that utilizes animal weights to estimate feed intake. Energy requirements were based on NRC (1984 and 1989)estimates. This model was validated by comparing output results to the predictive equations of other models. No actual data were used directly for validation. This model would require rigorous testing before it could be used with confidence.

Graze (Loewer, 1998) is a full-system simulation of grazing beef cattle production.

It is highly detailed, and includes parameters for breed, feeding systems, environmental conditions, grazing selections, reproductive performance, and herd dynamics, as well as physiological and cellular processes in the plants and animals. It was developed for a similar climate as the Cartwright and Sanders (1979) model but is claimed to be applicable to all types of climates. It has been observed to follow closely the carcass composition and animal requirements of the NRC (1996) model.

Currently, a dairy system model is being developed by Duynisveld , (1996). This system analysis models the nitrogen flow through an Atlantic Canadian dairy farm made up of four components: plant, animal, weather, and soil. It is still in the validation stage.

1.2.3 Plant and Pasture Production Models

Over the years, global climate change has altered the energy, carbon, and water fluxes of vegetation (Dale and Rausher, 1994). Modelling plant systems make it possible to understand and quantify growth harvest and plant interaction with other entities in the system. Diversity of plant species, inconsistent weather patterns, and many different managerial methods all contribute to the complexity of plant (forage) systems (Blackburn and Kothman, 1989).

Pasture related plant models (Table 2) have added complexity when it comes to describing growth and quality because of the plant/animal interaction. In order to relate animal production to pasture production, it is essential to estimate the quality in terms of animal digestibility. Fick et al. (1994) describe past modelling attempts to predict quality. They overview the earliest equations (starting in 1951) derived from experimental data to give empirical estimates of digestible dry matter.

Table 2. Plant and pasture production simulation models.

Model Focus	Model Prediction Objective(s)	Reference
Alfalfa and timothy	Estimates maturity	Bootsma, 1984
Alfalfa	Critical harvest date	Bootsma and Suzuki, 1985
Grass growth under grazing	Growth rate	Johnson and Parsons, 1985
Forage growth	Plant/animal production	Baker et al. 1992
Forages	Predicts flow of biomass of forages	Blackburn and Kothman, 1989
Pasture production	Plant/animal production	McCaskill and McIvor, 1993
Timothy	Dry matter, crude protein, ME	Gustavsson et al. 1995
Grass growth	Dry matter yields	Overman, 1995
Pasture	Plant/animal production	Cohen et al. 1995
Pasture production	Plant/animal production	Pleasants et al. 1997
Pasture growth	Grazing simulation	Moore et al. 1997
Pasture production	Plant/animal production	Riedo et al. 1998

These estimates were based on the chronological age of the crop with some attempt made to include the reproductive stage of the plant and environmental conditions. Several full plant/animal simulation models were developed in the 1960s and 1970s . Most of these models were based on specific locations and were not generalized.

Current investigations to find better ways of predicting forage quality have included the use of age and weather inputs to make the models more generalized and process orientated. Also, more rigorous testing of existing forage quality predictors is taking place with the reports of coefficients of determination (r^2) ranging from≈ 0.50 (age based) to≈ 0.60 (weather based) (Fick et al. 1994). It was concluded that more generalized and process models need to be developed and further consideration of the plant/animal interface is needed.

Blackburn and Kothman, (1989) proposed a deterministic model that simulates forage dynamics for different species of grasses. It was constructed to be sensitive to changes in rates of accumulation and disappearance of plant matter. The authors state that this model was designed to simulate the flow of biomass through the system so that it would be easier to integrate with animal performance models. Three species of plants were used to validate this model. It was concluded that it reflected reality and could be used in conjunction with animal models.

Overman, (1995) suggests that grass growth can be quantified by using the logistic growth equation. This is the most efficient way of predicting dry matter yields and nutrient uptake of grasses. Logistic growth, as proposed by Overman, (1995), was applied to field data for fescue grown in the southern United States. The author states that the model predicted the observed values well and that it had been extensively validated; however, there was no evidence of validation in the article.

Johnson and Parsons, (1985) developed a theoretical analysis of grass growth under grazing. The inputs used in this model are: daily light receipt of photosynthetic active radiation, mean daily temperature, and day length. This model has not been validated, but it provides a framework for future modelling efforts. The model was used to explore the consequences of differing stocking management on seasonal patterns of grass production and incorporates the established physiological responses to sward conditions and animal intake. The authors found there was no clear relationship between the seasonal pattern of grass growth and the utilization of the sward by ruminants. This model's advantage is in predicting growth under grazing; that is, it takes account of leaf area index and the rapid turnover of the plant material. Both of these factors are affected by cattle grazing.

A dynamic model by Gustavsson et al. (1995) was created to simulate the above ground dry matter growth, crude protein, and metabolizable energy in stands of timothy in relation to weather data, supply of fertilizer and soil fertility. The model simulates growth from early spring to first harvest. The authors state that the structure of the model would be adequate for temperate grasses but it would have to be modified for other types of grasses.

The model was validated using data from a climate that is similar to Atlantic Canada. The experimental test site supplied data on forage quality ,dry matter, soil fertility, and climatic conditions. This model is site specific but could be used in other areas provided it was properly calibrated.

Bootsma, (1984) used data from field trials in Atlantic Canada to estimate the growing degree days above 5 ° C required of several different forages. Alfalfa (*Parma* and *Iroquois*) and timothy (*Clair, Champ,* and *Climax*) were tested in trials at five different locations. The authors constructed two empirical equations to estimate maturity of the varieties and estimated day of first cut for the forage.

In 1985, Bootsma and Suzuki used similar equations to Bootsma ,(1984) to determine the probable variation in the critical fall harvest in Atlantic Canada, based on the growing degree-days accumulated for alfalfa. Using mean air temperature, in degrees

Celsius, the prediction equations helped improve winter survival of the crop through better timing of cutting and harvesting.

The model developed by McCaskill and McIvor, (1993) is used to determine the length of time that herbage is available to grazing animals. The main inputs in this model were: rainfall, evaporation, temperature, and water balance. Animal production was predicted in terms of live weight gains. The model was found to accurately predict herbage and animal production.

A computer decision support system was developed by Cohen et al. (1995) for range pasture, forage, and ruminant production. The plant model was driven by daily weather data and soil moisture budget. Consumption of forage by grazers and the production of live weight, fetus, milk, and wool are included in the system. The intake of the animal is based on the amount of quality plants available and the productive stage of the animal.

An example of a production model is 'Forage'. 'Forage' is a deterministic model, developed by Baker, (1992), with a plant/animal interface that predicts how changes in the sward characteristics affects feed intake and the diet selection of grazing animals. This grazing model is a function of: 1) the amount of forage demanded, 2) the amount of time needed to consume forage, and 3) number of bites needed to consume the forage. Sensitivity analyses were performed and revealed that the model was most sensitive to underestimation of parameters in the equations.

Pleasants et al. (1997) took a theoretical approach to simulate pasture biomass accumulation. They applied stochastic differential equations to simulate the stability and evolution of pasture growth over time. Variables that affect this system occured on different time scales. For example, depending on the stocking rate of the pasture, the mass decreases at a fairly rapid rate. However, the effects of soil fertility have a slightly slower effect on pasture growth. The study found with a 95% confidence, a 57 day period, under the outlined management situation, that pasture mass would move from 2 tonnes ha^{-1} to 1 tonnes ha^{-1}. A study such as this is useful for refining predictive models, but it is not applicable in practical situations.

One of the major limitations in many pasture models is that presence of multiple plant species is not accounted for. Riedo et al. (1997) developed a deterministic pasture model that simulates dry matter accumulation and fertilization (based on nitrogen, energy, and water balances) for a mixed-species perennial meadow. The model is driven by solar radiation, temperature, vapour pressure, wind speed, and precipitation. It was tested for a specific region in Switzerland but was subjected to extreme weather sensitivity testing. It was calibrated based on literature data and further validated with independent site data. The dry matter accumulation was overestimated by about 10% and net radiation was underestimated by about 56%. The model predictions were found not to be representative of the system when extreme weather (drought and flooding)conditions were specified.

The GrassGro model (Cohen et al. 1995) was further refined and applied to the decision support system component called Grazplan (Moore et al. 1997). The driving variables are solar radiation, maximum and minimum temperature, precipitation, potential evapotranspiration, and day length. A very detailed plant growth component was included in this model. Forage plants are recognized based on their morphology and ecology and legumes, grasses, and forbes are all represented. Plant material is also considered when determining feeding quality with classes including: live, dead, and litter. This model has been used and evaluated as a decision support system for producers in Australia.

The search for better farming strategies and improvements in production efficiencies and risk management demand a good knowledge about the processes in an agro-ecosystem (Lang et al. 1995). It is important to study farming systems as a whole, because like all ecosystems, every component interrelates with all the others. A great deal of research has been done on the individual components of pastoral farming, but too little has been done on evaluating the impact of technology on the whole farm operation (Allan and Scott, 1993). A major objective modelling is to identify the best possible strategy for any individual system (Pleasants et al. 1997).

1.2.4 Summary

The models reviewed in the two previous sections are, for the most part, limited to single components of the whole beef production system. The animal models have specific objectives and deal with specific experimental conditions. The main categories of animal models included digestive, intake, and animal requirement simulations. Overall, ruminant animal models have all been based on previously developed models. For example, the model by Fox et al. (1988) has been modified several times. The plant model types are growth, harvest, and quality simulations. There are a limited number of dynamic plant and soil models for a grassland environment.

Most pasture models that have been examined to date are specific for grass or animal production; rarely have there been attempts to model the whole system (Pearson and Ison, 1987). Twelve years later, there are still only a few whole beef production models and there are none that are specific to the Atlantic Canadian climate. There are a limited number of whole systems pasture-based models that evaluate animal, plant (single or multiple species), soil, and economic productivity.

1.3 Model Evaluation

Models, in the most pragmatic sense, are used to help agro-ecosystem managers select the most economical and ecological management practices for their individual situations. In order to use the model in this capacity, it is essential to realize the context or constraints of the model through model testing (Csaki, 1985; Gaunt et al. 1997). Model evaluation (or testing) with the greatest confidence involves a series of statistical and verification steps throughout the whole modelling exercise (Vanclay and Skovsgaard, 1997; France and Thornely, 1984).

This series of tests was outlined by Vanclay and Skovsgaard (1997) for growth models in general, but forestry growth models are used as an example. The following steps constitute an adequately tested model based on the research of these authors: 1) examination of the model's components in terms of logic and applicability to the study area; 2) determine the statistical performance of the model based on how it relates to the test data; 3) determine the fit of the model, and; 4) perform sensitivity analysis. The verification of the model is determined by examining its components and how they reflect reality based on knowledge of the system. Statistical performance of the model involves comparing the predicted data to the observed data in the form of regression analysis. Regression analysis will indicate the amount of variation explained by the model through probability testing, coefficient of determination, and slope and intercept estimates. Also, the random mean square error exercise will give a more refined level of detail to evaluate the performance of the model. Finally, sensitivity analysis indicates the influence of certain components of the model on the whole system. This testing system gives quantified results that can be compared to other models that have been tested to assess performance.

However, some argue that using regression statistical testing may be misleading, invalid, or inappropriate depending on the study (Mitchell, 1997). Mitchell (1997) suggests five reasons why regression analysis is not appropriate for validation of some models. The first is the general misapplication of regression. The intended use of regression is in a predictive capacity; validation is not a predictive exercise. Second, the null hypothesis testing is misleading; an F-test or t-test may indicate that there is a significant relationship when in actuality the variation is greater than what may be implied. Third, if a model has reached a point where serious testing is required, there is no doubt that there will be a significant relationship between the observed and predicted values. Therefore, the use of an F-test is not sensitive enough for the refined testing required. Fourth, the fitted line has no application. It is only a line-representation relationship between two sets of data. Finally, assumptions necessary for regression analysis are violated.

Mitchell (1997) concludes by presenting an alternative method that evaluates the model based on the deviation of the predicted from the observed data. A graph is used to indicate the precision of the model based on where, within a created envelope of values (confidence intervals), the predicted values fall. The author states this method is applicable to all types of models and gives a more objective basis for model evaluation. However, this was demonstrated only in the one documented case.

When describing the general requirements for modelling effectively, Gaunt et al. (1997) suggest that both methodologies presented above have a place in model evaluation depending on the complexity and objectives of the model in question. The general requirements for model evaluation include: ensuring separate data sets for calibration and validation, evaluating all model components individually, and using a quantitative and qualitative appraisal of model performance. It is advantageous to have large quantities of quality data, but this is often hard to realize. Therefore, it is suggested that characterization of the test data be completed before any recommendations are made.

It appears that an intimate knowledge of the model being evaluated and its objectives are required before a complete model evaluation is started. This will focus the model evaluation strategy and help to substantiate the conclusions.

Chapter 2:

A Description of Approach and Model Development for this Study

2.1 Approach

A system approach was used to develop a compartmental or component model of ME flow through a pasture-based beef production system in Atlantic Canada, herein referred to as the Atlantic Pasture based Beef Model (APBM). Previously developed models were utilized, along with reliable data, to represent the system.

2.2 Systems

2.2.1 Characteristics of a System

A system is a set of interrelated elements (High Performance Systems(HPS), 1994). Each part of a system is dependent on the other parts to define its behaviour (Neelamkavil, 1987). An agroecosystem is compromised of physical, biological, social, and economic subsystems.

The characteristics associated with systems are entities, attributes, interrelationships, and activities (Neelamkavil, 1987). The entities of a system are the participants. In an agricultural system, some examples of entities are its financial resources, human resources, animals, crops, and farm buildings. The attributes are the characteristics of the entities. For example, total farm income, number of people working on a farm, number of animals or hectares of crops, and the number of buildings, respectively, are attributes of entities. The interrelationships in the system represent how the entities relate to each other and to the system as a whole. For example, in an agricultural system, the number of animals on a farm relates to the amount of crop material needed to produce animal feed. Activities are the processes that change a system attribute. Selling or purchasing animals on a farm is an example of a process which alters the animal level attribute.

A dynamic system is one which has attributes that vary over time (Roberts et al. 1988). Over time, an attribute's quantity may increase or decrease. For example, a forage sward left to grow without grazing or harvesting will eventually become less productive. The decay of old plant growth and simultaneous shading of new growth is a dynamic process.

2.2.2 Pasture-based Beef Production Systems

The management of a beef herd is dependent on many different factors, including size, stage of production, age, and breed of the animals, along with the reproductive schedule, weather, and feed availability (Ward and Klopfenstein, 1991). It is important for the producer to assess all such factors in order to optimize production economically, as well as ecologically. Forages are the key feed ingredient for most Atlantic Canadian ruminant production systems (Kunelius et al. 1993). This is because of its availability as an economical and ecological feed resource in Atlantic Canada (Papadopoulos et al. 1993).

Animal production from grassland involves a system of interrelated entities (Wilkins, 1993). The flow of energy through the system initially involves the capture of solar energy by plant material. Plant material growth is facilitated by soil water and nutrients. The consumption of the plant material directly through grazing, or as conserved feed, provides the animal with the necessary energy and nutrients for survival and production.

Presently, there are four basic types of beef cattle production systems in Atlantic Canada (Nicholson et al. 1983): 1) The cow-calf foundation herd which produces breeding stock. Calves are born throughout the year and are weaned at approximately six months of age; 2) The cow-calf feeder herd employs commercial grade or crossbred cattle to produce a feeder. Spring calving is most common for this type of beef production and calves are weaned at 150-300 kg; 3) The cow-calf stocker herd which is similar to the feeder production system except the calves are kept through the winter with a desired weight gain of 0.4-0.7 kg per day; and 4) A finishing operation usually purchases cattle at feeder sales and finish the animal up to slaughter weight.

There are three types of pastures in Atlantic Canada (Butler et al. 1993). Permanent or naturalized pastures are those which have not been seeded for at least 20 years. They consist of naturalized species of legumes and grasses including bluegrass (*Poa pratensis* L.), bentgrass (*Agrostis* spp.), creeping red fescue (*Festuca rubra* L.), and white clover (*Trifolium repens* L.). Improved pastures are plots of land seeded as pasture or permanent pasture which have been seeded to include introduced species of grasses and legumes. Examples of improved species used in Atlantic Canada are timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* L.), tall fescue (*Festuca pratensis* Hud), and orchardgrass (*Dactylis glomerata* L.). The third type of pasture is called a supplementary pasture. This type is utilized when there is not enough regular pasture available for animal consumption. These pastures could be any type of crop that can provide nutritious feed for the animals.

The management of these pastures influences their productivity (Papadopopulos et al. 1993). The two basic grazing systems which are used for beef production in Atlantic Canada are rotational and continuous (Thomas and Goit, 1991). Rotational grazing divides the pasture into a number of small paddocks through which the animals are moved to maintain the optimal growth stage of the pasture plants. Continuous grazing allows the animals to graze at will in a large undivided pasture for an undetermined amount of time.

An important part of the beef production system involves the interrelationship between the grazing animal and the pasture plants. The interface of these two components represents one of the main subsystems in an animal/pasture production system. It is not possible to fully understand the whole system, or begin to model the growth of either of these components completely, without considering the relationship between them (Herrero et al. 1998).

2.3 Modelling

2.3.1 Introduction

In production agriculture, models are used for research, system assessment, and system description depending on the context of the model. Models are used to explain and illustrate a system's theoretical behaviour and evaluate potential management practices (Kothman and Smith, 1983).

2.3.2 Model Classification

A simulation model mimics the behaviour of the real system (Monteith, 1996). A simulation model can be a physical, mathematical, or computer model (Roberts et al. 1988). Mathematical simulations are most commonly used because of their flexibility and low cost.

Mathematical models use equations to represent the physical entities in real circumstances. Depending on the nature of the equations, and what they describe, models can be classified as empirical, mechanistic, stochastic, or deterministic. Empirical models are mathematical equations which are based primarily on laboratory and field experimentation, whereas the mechanistic models are based on the physical properties of the subject being modelled (Monteith, 1996). Illius and Gordon (1991) list the principal functions of simulation modelling as: 1) predicting the behaviour and the dynamics of a complex system, and 2) revealing where information is lacking in these systems. Stochastic models predict quantities based on the probable distribution of that event occurring (Thornely, 1976). Deterministic models predict without an associated probability and generally use mean values for calculation (Sorensen, 1998) .

2.3.3 Objectives in Modelling

Computer models are used to observe the possible outcomes of different management scenarios on a biological system (Bennett and Arnold, 1991). The compilation of large and varied sources of data can be used in association with mathematical equations and known physical properties to predict the functions of variables of the system under study. Based on the evaluation of the model, and the overall appraisal of the quality of the data sets it is possible to identify areas where further research is required.

2.3.4 Modelling Procedure

There are ten main steps used in the development of a simulation model (Roberts et al. 1988):

1) Problem definition;
2) System conceptualization;
3) Model representation;
4) Model verification;
5) Model sensitivity;
6) Model validation;
7) Model calibration;
8) Management analysis;
9) Identification of research needs;
10) Model revision and return to step one.

The initial step in simulation modelling is to identify and clearly define the problem that is to be studied. System conceptualization is a very important step in simulation modelling. In component models, system conceptualization involves diagrammatic representation of the system's entities and the interrelationships among them. The definition of the system, or the conceptualization, sets the limits and constraints of the model (Gaunt et al. 1997). Model representation involves translating the relationships among entities and their attributes, into a form which can interface with the software. In most cases, mathematical equations are used. The sensitivity of the model to a given variable is tested by examining the impact on model output when the value of one variable is changed while holding the values of other variables constant. The objective of this procedure is to discover which variable(s) affects the model output to the greatest extent.

Model verification requires the application of numerous tests to evaluate the model's ability to predict reality. Verification also involves ensuring that the model construction is correct through behavioural analysis.

Calibration involves manipulation of the model to represent a chosen historical set of data (Law and Kelton, 1982). Calibration is the process in which the model is set to conditions (including climate and soil) which are similar to the real system which it represents.

Validation of the model is necessary to determine the degree of agreement between the real system's behaviour and the prediction of the behaviour by the simulated model (Aburdene, 1988; Monteith, 1996).

Once the model has been assessed for its ability to reflect reality, it is then used to study the effects of different management factors on the system. Areas requiring future research can be identified during this analysis. The development of a model is an iterative process; as more information becomes available, alterations to the model are necessary, and all steps must be repeated.

2.4 Problem and System Definition

At the outset of modelling, it is essential to establish clear definitions of what is to be modelled, and the questions to be answered (Gaunt et al. 1997). The main objective of this study was to develop, evaluate, and utilize a model which represents a pasture-based beef production system. The system studied was a beef production system, based in Atlantic Canada (specifically Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland), that optimizes pasture utilization.

The flow of metabolizable energy (ME) was the specific area of interest for this study (Figure 1). The energy from the environment enters this system in the form of solar radiation, rainfall, and temperature. The pasture plants utilize the environmental inputs (along with many other inputs which will not be directly addressed in the context of this model) for photosynthesis, which provide the plants with energy for growth and development. The grazing animal then consumes the plant material, digests it, and receives the necessary energy required for maintenance, growth, pregnancy and lactation. The energy is removed from the system when the animals are sold.

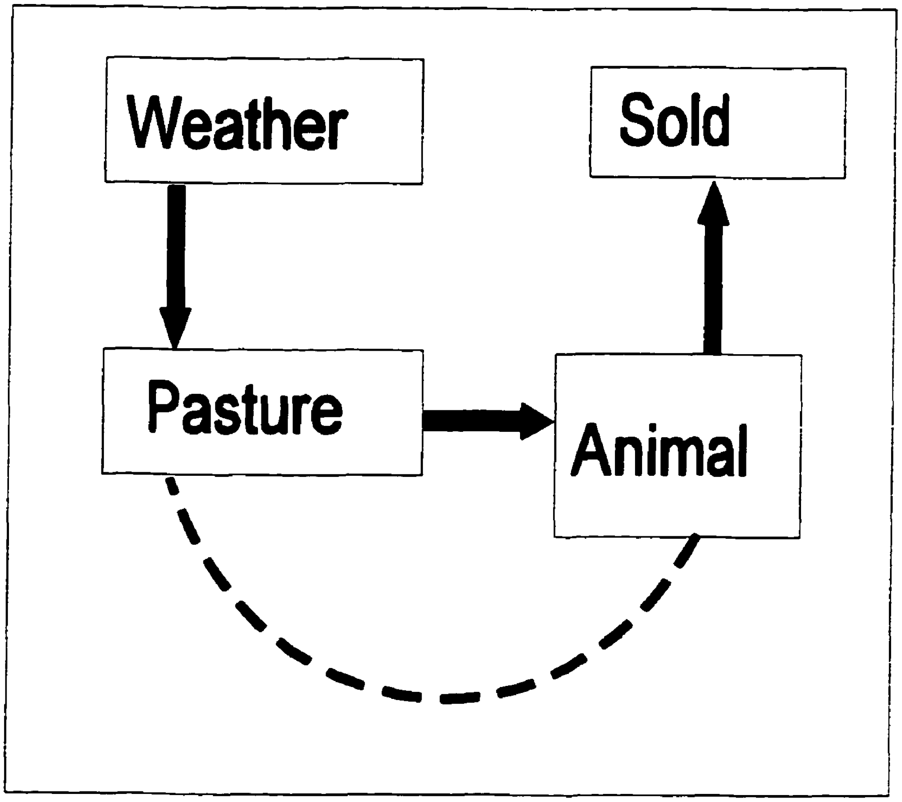

Figure 1. Overview of the flow of biological energy through a beef production system.

The dashed line (Figure 1) represents the effect the grazing animal has on plant ME production. The defoliation of plant material, selective grazing behaviour, crushing of plants, soil disturbance and nutrient distribution are some effects grazing animals have on pasture plant growth. Although there are several models which predict the dry matter accumulation, or growth of pasture under a grazing situation (Johnson and Parsons, 1985; Blackburn and Kothmann, 1989; Riedo et al. 1998 ; Pleasants et al. 1997) none of these have addressed the effect of grazing on the quality of the pasture in terms of ME.

For simplification purposes, the APBM did not account for the effect of grazing animals on pasture production. This assumption limits the applicability of this system simulation . Some conditions under which this system would be applicable are as follows: 1) low stocking rates of cattle, 2) short grazing period and 3) quick plant recovery.

The stocking rate (animals/ha) and grazing period dictate the grazing intensity. The APBM is applicable if the stocking rate is low and if the animals are only on the pasture for a short duration of time. If these two conditions are satisfied, then there will be minimal animal effect on pasture quality production.

The time it takes the plant to recover from defoliation must be rapid for APBM to be applicable (no animal effect on plants). Plant recovery, however, is dependent on external, and in many instances, uncontrollable variables such as environmental inputs. It is necessary for the plant to have adequate rainfall, solar radiation and soil nutrients for fast plant recovery.

The animal effect on pasture quality is an important relationship which must be investigated in order for the whole grazing system to be fully understood (Herrero, 1998). However ,for purposes of this simulation, the effect of the animal on ME production of the pasture plants was assumed to be none. The APBM is directly applicable only if the above mentioned conditions are in place.

The production of the plant ME, and the consumption and utilization of ME by the animal, are influenced by a large number of variables: direct, indirect, and interactive. The variables considered were dictated by the models chosen to represent the system. Those variables considered to influence the production of plant ME were: digestible fraction, ambient temperature, phasic plant development, soil available nitrogen, water index, crude protein, ash, canopy cover, biomass, and photoperiod. The main variables considered in the animal component were: plant ME, body weight, pasture activity, field conditions, temperature, breed, and production stage.

The system was further refined by clearly setting the limits of the model in reference to the management scenarios, time frame, animal breed, land utilization (plant species and pasture types), and production cycles (Table 3). The basic cow-calf production system was based on Cooper and Bosveld, (1989) and describes a typical Atlantic Canadian beef production system.

Table 3. Definition of management factors in APBM.

Factor	Definition
Breed	Hereford or Hereford cross
Herd	Cow-calf
Feed	Primarily pasture with some conserved forage
Calving times	Spring (April-May) Winter (January-February)
Pasture types	Naturalized - not seeded in 20 years or more Improved - seeded
Climate condition	Atlantic Canada
Grazing management	Rotational (move cattle as necessary)
Production cycle	2 years
Stocking rate	1.5 animals/ha

Breed variation was an important consideration. Different breeds of cattle may have basic physiological differences and may perform differently in certain climates and production systems (NRC, 1996). In this case, the Hereford or Hereford cross was chosen as the representative breed of cattle used in an Atlantic Canadian beef production system.

The time structure was based on a cow-calf operation spanning a two-year production cycle (Figure 2). Typically, the cow is bred either in March or August, depending on the desired time of calving, winter or spring, respectively, or approximately 83 days after calving (NRC, 1996). The calf suckles the cow to weaning where it may be sold or retained until the finished stage. If the calf is a good quality heifer, she may be kept as a replacement heifer and bred at approximately 15 months of age.

The climatic conditions were based on Environment Canada, (1998) Canadian Climate Normal(CCN) for the Truro region. The CCN gives the average weather conditions and the associated standard deviation by region of Canada. Some of the variables summarized over the past 30 years in the CCN are rainfall (mm), minimum and maximum temperature (° C), and solar radiation (hours, and potential evapotranspiration (mm)).

The grazing management was defined as a rotational system. The animals were kept on a paddock only as long as there was enough available herbage to maintain a productive pasture, and which allowed for a sufficient dry matter intake for the animals. For analysis purposes the animals were placed on two different types of pasture at a stocking rate of 1.5 animals/ ha, based on the report by Laflamme et al. (1988). As animals grow, more pasture mass is required. Therefore, it was assumed that the number of paddocks required was increased as needed. The pastures were defined as: 1) Naturalized - characterized by bluegrass, creeping red fescue, and bentgrass, and ;2) Improved or seeded - characterized

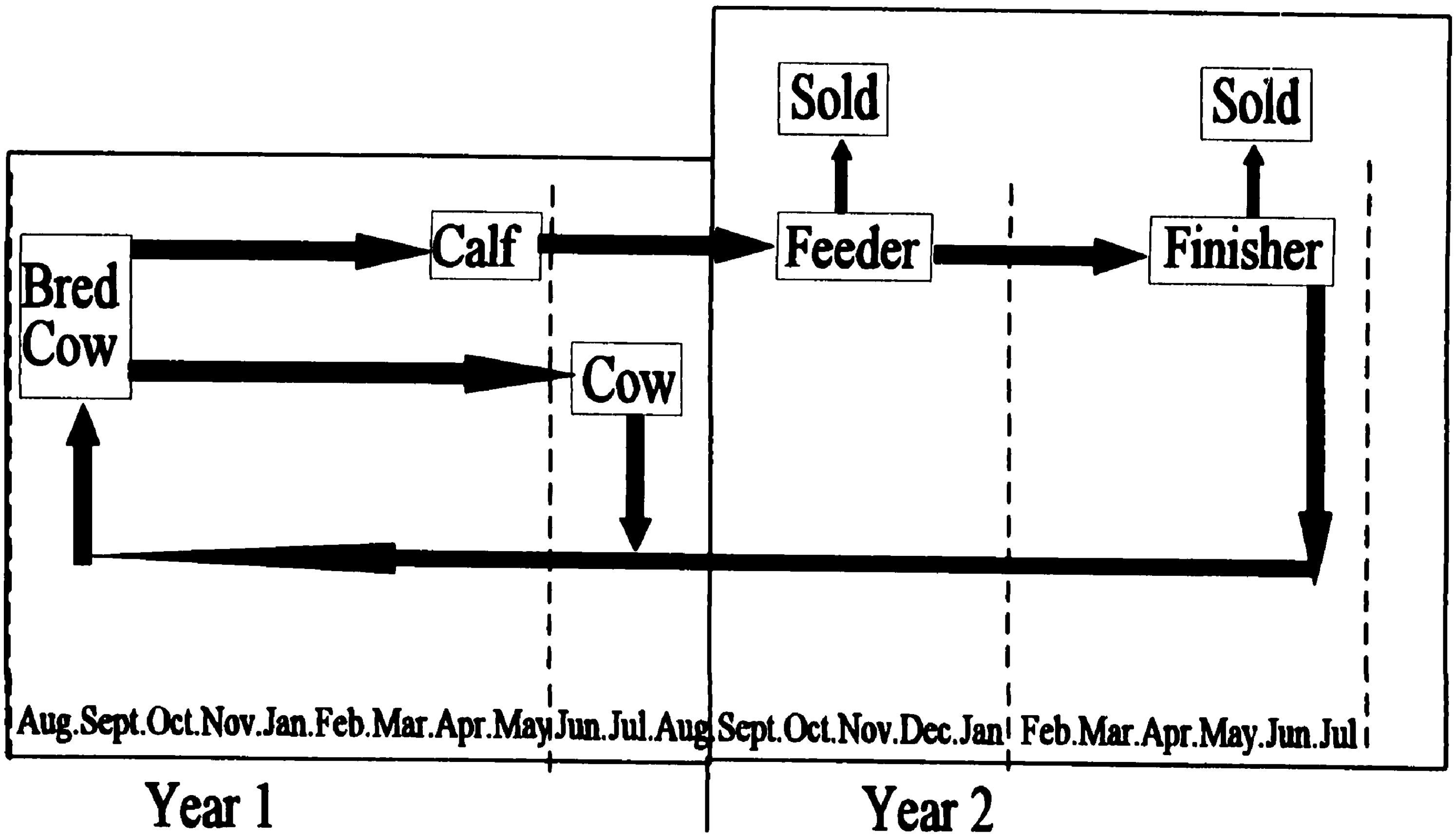

Figure 2. Two year cow-calf beef production cycle.

by timothy, tall fescue, and orchardgrass. These characteristic pasture compositions were based on documented pasture definitions for Atlantic Canada (Butler et al. 1993).

The system definition as outlined set the limits of the model and the context of model prediction. To facilitate model construction and evaluation, several assumptions (Table 4) were made and also must be considered when assessing the model's context.

Table 4. System assumptions for the plant, animal, and weather components.

Component	Assumptions
Plant	Native pasture: bluegrass, creeping red fescue, and bentgrass.
	Improved pasture: timothy, tall fescue, and orchardgrass
	Soil factors such as N and water are not limiting factors and are consistent.
	Animal grazing has no direct effect on grass growth.
Animal	One animal representative of each production stage (yearling, calf, lactating, and pregnant).
	If the pasture does not give adequate nutrition, a supplement is provided.
	There is always adequate pasture mass available to the animals.

2.5 Model Design

2.5.1 Introduction

The APBM was developed by applying previous models to the system concept. It has three main components: 1)Plant; 2) Animal; and 3)Weather. Existing models were examined for their applicability to this study on a component basis; separate models were used for each of the individual components. To simulate the overall system, all three models were combined. As the focus of the system was the flow of ME, the ability of the models to predict and/or utilize ME was the main criterion in model selection. The models were translated into one common modelling language: Stella Research 5.1 (HPS, 1998).

2.5.2 Plant Component

The plant component of this system was based on a timothy (*Phleum pratense*) production model by Gustvasson et al. (1995). It simulates the biomass production, crude protein, and ME of timothy on a daily time step. This model was chosen for four main reasons: 1) The model's ability to predict ME and biomass on daily time step using weather inputs such as rainfall, ambient temperature, and photoperiod; 2) It was developed and validated in an area with a climate similar to Atlantic Canada; 3) The authors' statement of the model's potential to simulate growth and development of grass species other than timothy in different climates, and; 4) The model was being used to develop an Atlantic Canadian dairy production model (Duynisveld , 1996).

The following equations were translated into Stella 5.1 (HPS, 1998) code(Table 5) (Numbers contained in parentheses correspond with the equations contained in this Table 5).The daily fluctuations of biomass, crude protein, and ME were predicted based on equations which utilize variables and initial values set by the authors (Table 6) including environmental conditions, nitrogen concentration of plant tissue, and soil water status. For the graphical representation of the plant component (Figure 4), translation required multiple Stella 5.1 (HPS, 1998) entities to be assigned to the individual variables (Table 7).

The phasic development (1) simulated the plant daily physiological development from the inputs of temperature and photoperiod. The constants λ and τ (photoperiod and temperature) were the minimum values necessary for phasic development to occur.

Table 5. Model development equations for the Plant component based on Gustavasson et al. (1995).

Equation	Variable	Gustavasson et al. (1995)	Stella code
1	Phasic development	$\Delta D_i = \delta \times 10^{-4}(t_i - \tau)(p_i - \lambda)$ where $t_i > \tau$ and $p_i > \lambda$	`if(day=365)then(IF(init(Actual_temp)>=Tim_temp)AND(init(photoperiod)>=timphoto)THEN(0.00032*(init(Actual_temp)-Tim_temp)*(init(photoperiod)-timphoto))ELSE(0))else(IF(Actual_temp>=Tim_temp)AND(photoperiod>=timphoto)THEN(0.00032*(Actual_temp-Tim_temp)*(photoperiod-timphoto))ELSE(0))`
2	Soil water	$Sw_i = Sw_{i-1} + p_i - ET_i$	`IF(day=90)THEN(available_water-INIT(available_water))ELSE(PET-Evap)+(IF(available_water>250)THEN(available_water-250)ELSE(0))`
3	Evapo-transpiration	$Et_i = C_i{*}Ep{*}WI$	`Canopy_Cover*PET*water_index`
4	Temperature index	$1/\{1+\exp(-\chi(t_i-\theta))\}$	`(1/(1+EXP((-.6)*(Actual_temp-8.5))))`
5	Nitrogen maximum	$N_{maxd}=N_{max0}(\exp(-\beta_{max} D_i))$	`if(day=365)then((.07)*(EXP(-1.3*INIT(Change_in_development))))else((.07)*(EXP(-1.3*Change_in_development)))`
6	Nitrogen minimum	$N_{mind}=N_{min0} (\exp(-\beta_{min} D_i))$	`if(day=365)then((.025)*(EXP(-1.6*init(Change_in_development))))else((.025)*(EXP(-1.6*Change_in_development)))`
7	Maximum uptake of nitrogen	$[W_{i-1} (N_{maxd}-N_{i-1}/W_{i-1})/\omega]$	`if(day=365)then(IF(init(Biomass1)=0)THEN(0)ELSE(((init(Biomass1))*(((init(Nmax)-init(Nout))/(init(Biomass1)))/.6))))else(IF(Biomass1=0)THEN(0)ELSE(((Biomass1)*(((Nmax-Nout)/(Biomass1))/.6))))`
8	Relative nitrogen concentration	$(Ni/W_{i-1} - N_{mind})/(N_{maxd} - Nmin_d)$	`if(day=365)then(IF(init(Biomass1)=0)OR(init(Nin)=0)THEN(0)ELSE(((init(Nin)/init(Biomass1))-init(Nmin))/(init(Nmax)-init(Nmin))))else(IF(Biomass1=0)OR(Nin=0)THEN(0)ELSE(((Nin/Biomass1)-Nmin)/(Nmax-Nmin)))`
9	Nitrogen index	$(1-\exp(-\nu RNC_i)/1-\exp(-\nu))$	`if(day=365)then((1-(EXP(-8*(init(RNC)))/(1-EXP(-8))))else((1-(EXP(-8*(RNC))/(1-EXP(-8)))))`
10	Ash	$6.9+0.14CP$	`if(day=365)then(6.9+(0.14*init(CP)))else(6.9+(0.14*CP))`
11	Organic matter	$W_i(1.0-0.01Ash_i)$	`if(day=365)then(Init(Biomass)*(1.0-0.01*init(ASH)))else(Biomass*(1.0-0.01*ASH))`

Table 5. Continued

Equation	Variable	Gustavasson <u>et</u> <u>al</u>. (1995)	Stella code
12	Non-digestible organic matter	$\phi Om_i D_i \times 10^{-2}$	`if(day=366)then((((OMPAR*init(OM)*(Change_in_development))*(.01))*50))else(if(OM=0)then(0)else(((OMPAR*OM*Change_in_development)*(.01))*50))`
13	Digestible organic	$100\text{-}100*F_i/Om$	`if(day=365)then(IF(init(OM)=0)THEN(0)ELSE(100-(100*(init(NDOMPOOL)/init(OM)))))else(IF(OM=0)THEN(0)ELSE(100-(100*NDOMPOOL/OM)))`
14	Metabolizable energy	$(0.16DOM_i -1.91)(1.0\text{-}0.01 Ai)$	`if(day<=100)or(day>=360)then(0)else(if(day=365)then(((((((0.16*init(DOM)-1.91)*(1.0-0.01*init(ASH)))*4.184))))/18.875)else(((((((0.16*DOM-1.91)*(1.0-0.01*ASH))*4.184))))/18.875))`
15	Biomass	$C_i \varepsilon R_i WI_i TI_i NI_i - \Upsilon(Om_{i\text{-}1} - F_{i\text{-}1}) Q_{10}^{(Ti\text{-}15)/10}$	`If(Canopy_Cover=0)then(0)else((if(day=365)then((((((((((init(Canopy_Cover)*1.5*init(Solar_Radiation)*init(ni)*init(water_index)*init(temperature_index)))))-(0.015*(init(OmPool)-init(NDOMPOOL))*(1.5^((init(Actual_temp)-15)/10))))))/1000)*10000))else((((((((((Canopy_Cover*1.5*Solar_Radiation*ni*water_index*temperature_index))))-(0.015*(OmPool-NDOMPOOL)*(1.5^((Actual_temp-15)/10))))))/1000)*10000))))`
16	Canopy cover	$(W_{i\text{-}1}/ W_f)^{0.5}$	`if(Biomass=0)then(0)else(if(day=365)then((init(Biomass)/WF)^.5)else((Biomass/WF)^.5))`
17	Crude protein	RNC*6.25	`if(day=365)then(if(init(Biomass)<=.5)or(Biomass<=.5)then(0)else((6.25*Npool2)/init(Biomass))else(if(Biomass<=.5)then(0)else((6.25*Npool2))))))/Biomass)`

Table 6. Variables (Gustavsson et al. 1995) and initial values.

Variable Name (Gustavsson et al. 1995)	Symbol	Equation (Table 5)	Value
Dry matter (full cover)	W_f	16	250
Radiation use efficiency	ε	15	1.5
Ash content intercept	-	10	6.9
Ash content slope	-	10	0.14
Critical photoperiod	λ	1	14
Development rate constant	δ	1	3.2
Respiration response	Q_{10}	15	1.5
Maintenance respiration	γ	15	0.015
Reference temperature (Q_{10})	-	15	15
Organic Matter Accumulation	ϕ	12	1.69
Base temperature	τ	1	5
Nitrogen response	υ	9	-8
Temperature response curve	κ	4	0.6
Midpoint temperature	θ	4	8.5
Proportion of nitrogen in above ground plant material	ω	7	0.6
Decline in maximum nitrogen	β_{max}	5	1.3
Decline in minimum nitrogen	β_{min}	6	1.6
Intercept for maximum nitrogen	N_{MAXo}	5	0.07
Intercept for minimum nitrogen	N_{MINo}	6	0.025

Values used for critical photoperiod and base temperature (λ=14 hours and τ= 5° C respectively) were based on values used in previous models for temperate grasses. Gordon and Bootsma, (1993) found similar base temperature values effective in their research conducted in Atlantic Canada, therefore those values were retained. The authors derived

Table 7. Gustavsson et al. (1995) variable and corresponding Stella 5.1 (HPS, 1998)entities.

Variables	Name of Entity (Figure 3)	Entity Classification
Phasic development	Actual temp	convertor
	timtemp	convertor
	photoperiod	graphical function
	change in development	flow
	Development	stock
Soil water	available water	stock
	PET	convertor
	Evap	flow
Evapotranspiration	Canopy cover	Stock
	PET	convertor
	Water index	graphical function
	Actual temp	convertor
Temperature index	Actual temp	convertor
Nitrogen maximum	Change in development	stock
Nitrogen minimum	Change in development	stock
Maximum uptake of nitrogen	Biomass1	stock
	Max.	convertor
	Not	flow
Relative nitrogen concentration	Biomass	stock
	Nmin	convertor
	Max.	convertor
Ash	cp	convertor
Non-digestible organic matter	ndom	flow
	change in development	stock
Digestible organic matter	om	flow
	NDOMPool	stock
Metabolizable energy	DOM	convertor
Biomass	water index	graphical function
	temp index	graphical function
	Ompool	stock
	NDOMpool	stock
	Actual temp	convertor
Canopy cover	Biomass	stock
	Wf	convertor
Crude protein	Biomass	stock
	Npool2	stock

the phasic development rate constant (δ= 3.2/day) from timothy field data collected for model development. The soil water balance (2) was simulated utilizing rainfall as the only source of water and evaporation as the only subtraction of water. A value of 250mm, obtained from experimental data, was assumed to be the amount of plant available water in 1.0m of soil (Gustavsson et al. 1995) . Of the plant available soil water, 40% is depleted and unavailable to the plant (Gustavsson et al. 1995). It was assumed that the remaining 60 % of that water was used for the estimation of water effects on plant growth in the form of a water index. The amount of water evaporated (3) from the plant was based on the potential evaporation and the canopy cover. The soil water status of the model was adapted from the Duynisveld, (1996) dairy production model developed for the same region of Canada. Soil characteristics were not directly considered in this model and soil quality was assumed to be adequate at all times.

The temperature index (4) simulated the effect of low temperatures on plant growth. As the temperature increased, the plant growth increased. However, in reality this is not necessarily the case. If the temperature goes up too high, plant growth may cease. This was accounted for in the biomass accumulation equation (15) in terms of plant respiration. Respiration was simulated in reference to 15° C; as the temperature increased 10° C over the 15° C reference temperature, the amount of respiration required was 1.5 times that which was needed below that reference temperature.

Nitrogen (N) maximum (5) and N minimum (6) gave the upper and lower limits for nitrogen concentration in the plant material. In the form of a logistic equation, the limits used the intercepts of 1.6 (upper) and 1.4 (lower), phasic development, and the initial N concentration to generate the change over time. The maximum N limit represented a situation where there was enough N for plant growth to proceed normally, whereas the minimum concentration indicated there was not enough N available for plant growth.

The nitrogen in the plant was assumed to be 60% of the maximum available for uptake (7). The difference between the current N concentration and the maximum concentration was then multiplied by the biomass to express the amount of N available to the plant. To examine the effect of N on the growth of the plant at any given stage of development, the relative nitrogen concentration curve was generated (8). This equation used the upper and lower limits of N and biomass to illustrate the effects on plant growth in the form of a nitrogen index (9). This curve shows that as N increased, the amount of growth also increased, up to a point. From this point, as N increased, the growth rate started to diminish. If there was no plant material (biomass=0), then it was necessary to indicate that the N uptake would be zero.

The overall output of nitrogen was required to be in terms of the crude protein (17). The amount of crude protein in the above ground plant material was calculated by multiplying the nitrogen content in the plant by 6.25 (Association of Official Analytical Chemists, 1984). This value, divided by the amount of biomass, resulted in a crude protein value on a per kg basis.

Metabolizable energy (14) was calculated using digestible organic matter and ash content. Overall, this model took into account short-term fluctuations as well as seasonal changes in ME. Short-term fluctuations were simulated from daily temperature and radiation. When the plant component was interfaced with the animal component, it was necessary to restrict the production of ME to the days when the animals were on pasture. This was due to the fact that the ME produced from the plant component model was linked directly to the animal component model.

It was necessary to use an adjustment factor in the model to obtain realistic values for ME. The ME output was divided by 18.875 for naturalized pastures and 18 for improved pastures. These values were obtained through calibration exercises. Also, it was necessary to multiply the ME equation by 4.184, as the original model predicted in terms of mega joules(MJ). In order to interface the plant component with the animal component, units of mega calories (Mcal) were required.

In order to estimate ME production, ash content was required. An empirical estimation of ash based on crude protein content was used. The coefficient of determination (r^2) associated with this prediction was 0.42 with a standard error of estimation associated with this prediction of 0.82.

The organic matter calculation (11) used the total amount of biomass and the percentage ash. The amount of digestible organic matter (13) was a function of the percentage of organic matter in relation to the amount of non-digestible organic matter (12). As the pasture season progressed, the amount of non-digestible material increased in relation to the organic matter and phasic development. The constant 1.69 was multiplied by the organic matter, indicating the non-digestible fraction increased at a slightly faster

Table 5. Continued

Equation	Variable	Gustavasson et al. (1995)	Stella code
12	Non-digestible organic matter	$\phi Om_i D_i \times 10^{-2}$	if(day=366)then((((OMPAR*init(OM)*(Change_in_development))*(.01))*50))else(if(OM=0)then(0)else(((OMPAR*OM*Change_in_development)*(.01))*50))
13	Digestible organic	$100-100*F_i/Om$	if(day=365)then(IF(init(OM)=0)THEN(0)ELSE(100-(100*(init(NDOMPOOL)/init(OM)))))else(IF(OM=0)THEN(0)ELSE(100-(100*NDOMPOOL/OM)))
14	Metabolizable energy	$(0.16DOM_i -1.91)(1.0-0.01 Ai)$	if(day<=100)or(day>=360)then(0)else(if(day=365)then(((((((0.16*init(DOM)-1.91)*(1.0-0.01*init(ASH)))*4.184))))/18.875)else(((((((0.16*DOM-1.91)*(1.0-0.01*ASH))*4.184))))/18.875))
15	Biomass	$C_i \varepsilon R_i WI_i TI_i NI_i - \Upsilon(Om_{i-1} - F_{i-1}) Q_{10}^{(Ti-15)/10}$	If(Canopy_Cover=0)then(0)else((if(day=365)then((((((((((init(Canopy_Cover)*1.5*init(Solar_Radiation)*init(ni)*init(water_index)*init(temperature_index)))))-(0.015*(init(OmPool)-init(NDOMPOOL))*(1.5^((init(Actual_temp)-15)/10))))))/1000)*10000))else((((((((((Canopy_Cover*1.5*Solar_Radiation*ni*water_index*temperature_index))))-(0.015*(OmPool-NDOMPOOL)*(1.5^((Actual_temp-15)/10)))))))/1000)*10000))))
16	Canopy cover	$(W_{i-1}/W_f)^{0.5}$	if(Biomass=0)then(0)else(if(day=365)then((init(Biomass)/WF)^.5)else((Biomass/WF)^.5))
17	Crude protein	RNC*6.25	if(day=365)then(if(init(Biomass)<=.5)or(Biomass<=.5)then(0)else((6.25*Npool2)/init(Biomass))else(if(Biomass<=.5)then(0)else((6.25*Npool2))))))/Biomass)

rate, depending on the stage of development.

The canopy cover (16) at any given time was estimated from the amount of above ground biomass. The biomass divided by a constant (W_f) of 250 (assumed to be maximum coverage) gave a percentage of canopy cover for that crop (Gustavsson et al . 1995). The cover value was then used for the calculation of the current biomass production (15). Accumulation of biomass was influenced by canopy cover, solar radiation, water availability, temperature effect, nitrogen supply, and the amount of plant respiration (in relation to temperature and plant material). The original biomass calculation was reported in grams/meter square (g /m^2) but for this simulation it was calculated as kilograms/hectare (kg/ha) basis. Therefore, the conversion factors 1000 and 10000 were used in this calculation.

The simulation ran for two years, so it was necessary for all sections of the model to have conditions initialization on day 365 to reset all variables to their original state. This was because the original plant model was intended only for one production year. The plant model was then coupled with the animal model directly by the ME output of the plant component .

2.5.3 Animal Component

The animal component of this beef production simulation was based on the NRC (1996) model. NRC (1996) divides the animal component into four production stages: 1) lactating cow; 2) pregnant cow; 3) yearling, and; 4) calf. Energy and protein requirements are addressed as the two main factors which influence animal growth.

The APBM retained the four production-stage structure of lactating, pregnant , yearling and calf, and then translated the equations into Stella 5.1 (HPS, 1998) code

(Tables 8, 9, 10, and 11 respectively in the text numbers contained in parentheses refer to equations contained in these tables). These were represented graphically in terms of the Stella 5.1 (HPS, 1998)entities (Figures 5, 6, 7, and 8, respectively,). As the APBM focussed on the flow of biological energy through a beef production system, the protein requirements were assumed to be sufficient. The model used a basic structure of equations and parameters for all production stages. Additional equations were used, as needed, to differentiate between the animal production stages. The simulation used for this research assumed that during the 2 year time span there was one representative animal for each production stage.

The animals received energy for growth and maintenance through an intake function. The dry matter intake (DMI) equations (22, 48, 69, and 85) were of similar structure for all animal production stages, with specific parameters values assigned for each. The DMI equation was based on several physiological and environmental factors, and was adjusted for size of animal, body fat, sex and production stage. The body fat adjustment factor chosen for this study was 0.97 (NRC, 1996). Breed size was also a consideration, as some breeds tend to be larger and therefore require more dry matter. The breed adjustment factor for Hereford was 1.04 (NRC, 1996). Sex of the animal is assumed to affect intake; a male animal usually requires a larger amount of dry matter. Finally, as there were no growth enhancing substances used in this study, no adjustment factors were included.

Environmental elements accounted for included mud amounts (parameter named: Mud), and a temperature effect. In the APBM, the amount of mud was assumed to be minimal (10-20cm), so the lower value (mud=0.85) for that effect was chosen, indicating that the DMI for these animals was only slightly reduced. The temperature effect (Appendix B) was simulated using a graphical function. The temperature ranges given by NRC(1996) were correlated with the actual temperatures being simulated by the weather component.

The equations for DMI were given parameters for each of the production stages. These equations were validated by NRC(1996) using 12 years of experimental data. The results showed that for an all-forage diet in a feedlot management scenario, the equation accounted for 31% of the variation in forage intake. For animals fed a diet higher in concentrate, it accounted for approximately 75% of the variation.

To simulate a production change in the animals, a special condition was placed on the DMI of the calf (65) and pregnant cow (83). Calves are typically weaned at approximately 200 kg liveweight , so at this time the intake would change to an intake similar to the yearling(46). The intake of the pregnant cow changed after day 94 of the pregnancy. Previously, its intake was the same as that of a lactating cow but without the adjustment factors for lactation and milk production.

The energy consumed by the animals in this simulated system was supplied solely by the ME output of the plant component or a basic diet with an ME value of 1.95 Mcal/kg (NRC, 1996) when the pasture was not available. The NRC (1996) uses a NE system developed by Lofgreen and Garrett (1968) to partition the energy into maintenance energy (NE_m) and net energy available for weight gain (NE_g). The NE_m (19) and NE_g (20) values for animal production were calculated using an empirical formula and the ME input from the plant. The empirical formula was also used to partition the energy from milk available to nursing calves (66, 67). These relationships were developed from comparative slaughter studies. The condition score of the animal was assumed to be 5 (on a 1-9 scale) and changed with fluctuations in body weight.

For animals on pasture, there were three basic energy requirements: maintenance (22, 48, 69, and 85), gain (40, 54, 79, and 93), and activity on pasture (23, 47, 70, and 86). Other energy sinks such as cold stress (25, 51, 72, and 88), milk production (29), and pregnancy (101) were calculated depending on the environmental conditions and production stages. These equations were developed from long-term feeding trails and comparative slaughter experiments.

NE_m was influenced by animal size, breed, production stage, sex, condition score, and current temperature. The breed effect on these requirements was based on the frame size. For a female, an adjustment factor of 1 was used, and for males an adjustment factor of 1.15 was used (NRC, 1996). Lactating animals require extra energy, therefore, the equation was multiplied by 1.2 to account for the increased requirement (NRC, 1996). Pregnancy energy requirements were added to the maintenance level, where applicable, as extra energy was required for fetal growth. The average calf birth weight for a Hereford was 36 kg (NRC, 1996).

For animals on pasture, the energy requirement increased due to increased movement and climate effects. The increased activity was calculated using the animal body weight, nutrient composition of pasture (37), and the amount of pasture available for consumption (also an output from the plant component). If the pasture land was considered to be hilly, the equation was multiplied by 2, and if it was flat, it was multiplied by 1 (NRC, 1996). Pasture land for beef cattle in Atlantic Canada is usually marginal land that can not easily be used for other crops. For this study, a value of 1.5 (between 1 and 2) was chosen to represent the terrain.

In this model, the largest climatic effect on the animals was the temperature. Cold stress increased the amount of energy needed by the animal. It was based on the animal's surface area (26, 50, 73, and 89) and its lower critical temperature (43, 53, 81, and 94) which was calculated from the animal's internal and external insulation. The internal insulation (27, 55, 75, and 90) and external insulation (27, 57, 76, and 90) values were based on haircoat, mud factor, wind factor, and condition score of the animal. The amount of heat produced by the animal contributed to the overall energy status. Heat production (44, 60, 82, and 95) was calculated by subtracting the total energy being retained for production (weight gain, pregnancy, and milk) and maintenance from the total ME intake (45) and dividing it by the total surface area of the animal (m^2). In other words, the excess energy not used by the animal was released in the form of heat.

Weight change in the animals was based on a standard reference weight (SRW) system. The standard reference weight used for the APBM was 478 kg (NRC, 1996). The daily weight gain for all production stages was calculated from the amount of retained energy (28, 59, 77, and 91). The retained energy was calculated by subtracting the intake required for maintenance (24, 58, 71, and 87) from the total DMI, then multiplying by the energy available for gain (NE_g). From this calculation it was possible to evaluate the weight gain (38, 54, 80, and 93) on a kg basis by multiplying by the equivalent shrunken body weight (33, 61, 78, and 92).

The relationship between shrunken weight and energy requirements were developed from a series of slaughter trails and whole body composition analysis(Lofgreen and Garrett, 1968). The weight gain calculation was validated with three large data sets (NRC, 1996). Based on these trials the model accounted for between 50-67% of the variation in the observed weight gain data.

The animal production calculations described above were used to represent all production stages, in general, with specific parameters for each production stage. A general calculation for shrunken body weight (41) and equivalent shrunken body and empty body weight (32 and 33) were applicable to all animals. The initial weight was according to the individual animal production stage. However, some special calculations were required for the pregnant and lactating animals. The energy in the milk (30) was calculated based on literature values of the percentage fat and non-fat solids in Hereford milk(NRC, 1996). The amount of milk produced daily was based on a table of values of a standard lactation curve and is represented in Stella 5.1 (HPS, 1998) as a graphical function (Appendix C) . The fetal growth (98) and conceptus weight (99) were calculated from a calibrated general growth curve and expected birth weight.

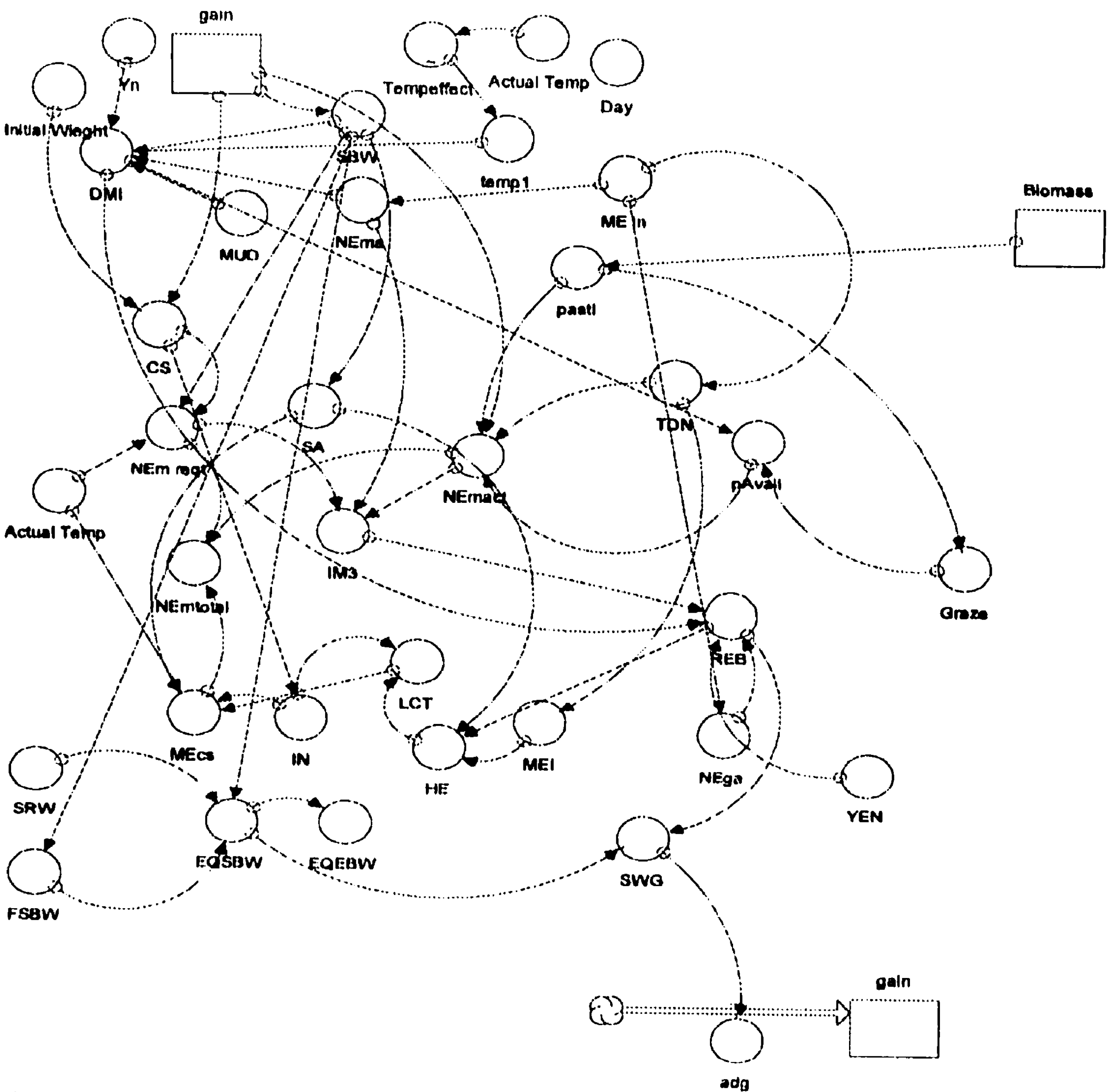

Figure 4.Lactating cow component as it appears in Stella 5.1(HPS, 1998).

Table 8. Model development equations for the Lactating Cow component based on NRC (1996) .

Number	Variable name	NRC (1996)	Stella code
18	Dry matter intake	$(SBW^{0.75}*(0.04997\ NE_{ma}^{2} + 0.03840)/NE_{ma})(Temp1)(Mud) +0.2MM)$	if(NEma<=1)then((((SBW^0.75)*(0.04997*.95^2+0.03840)/.95)*(temp1*MUD+(.2*Yn))))else(((SBW^0.75)*(0.04997*NEma^2+0.03840)/NEma)*(temp1*MUD+(.2*Yn)))
19*	Net energy available for maintenance	$((1.37*ME-0.138*\ ME^{2} +0.0105*ME^{3} -1.12))$	((1.37*ME_in-0.138*ME_in^2+0.0105*ME_in^3-1.12))
20*	Net energy available for gain	$(((1.42*ME-0.174*\ ME^{2} +0.0122*\ ME^{3} -1.65)))$	(((1.42*ME_in-0.174*ME_in^2+0.0122*ME_in^3-1.65)))
21	Condition score	input variable	5+((gain-Initial_Wieght)/50)
22	Net energy required for maintenance	$[(0.077\ SBW^{0.75}(BE)(L)(sex)\ (0.8+((CS-1)*0.05))))] + ((0.0007)(20-Tp))$	((0.077*(SBW^.75)*1.2*(.8+((CS-1)*.05))+(.0007)*(20-Actual_Temp)))
23	Net energy required for activity	((0.006*pl*(0.9-(TDNp/100))) +(0.05*terrain/(pavail+3)))*BW/4.184	if(pastl<=0)then(0)else(((.006*(pastl)*(.9-(TDN/100))+0.05*1.5/((pAvail)*3)*(gain/4.184)))
24	Intake required for maintenance	$(NE_{m} +NE_{mact})/(NE_{ma}*ADTV)$	if(NEma<=1)then((((NEm_reqt+NEmact)/.95)))else((((NEm_reqt+NEmact)/NEma)))
25	Energy required for cold stress	SA(LCT-Tc)/IN	SA*(LCT-Actual_Temp/IN)
26	Surface area	$0.09*SBW^{0.67}$	0.09*SBW^.67
27	Insulation	TI +EI	((7.36-(.296*5)+ (.55*2.55)*(CS*.75)*.2))
28	Retained energy	$(DMI-Im)*NE_{ma} -YE_{n}$	IF(NEga<=0)then(0)else(((DMI-IM3)*NEga)-YEN)

Table 8. Continued

Number	Variable name	NRC (1996)	Stella code
29	Net energy for milk	Yn *E	Yn*E
30	Energy	(0.092*fat %)+(0.049 *SNF %)- 0.0569	0.72105
31	Milk production	Tabular values	Graphical function
32*	Equivalent empty body weight	0.891*EQSBW	EQSBW*0.891
33*	Equivalent shrunk body weight	SBW*(SRW)/(FSBW)	(SBW*(SRW/FSBW))
34*	Graze	$(0.17IPM-0.000074\ IPM^2+2.4)/100$	((0.17*pastI-0.000074*pastI^2+2.4)/100)
35*	Initial pasture mass	input value	if(Biomass<=0)then (1)else(Biomass)
36	Available forage	input value	DMI*Graze
37*	TDN pasture	input value	if(ME_in=0)then(0)else((ME_in*.82)/.044)
38	Shrunk weight gain	$13.91\ RE^{0.9116}EQSBW^{-0.6837}$	if(REB<=0)then(0)else(13.91*(REB^.9116)*EQSBW^-0.6837)
40	Weight gain	SWG	SWG
41*	Shrunk body weight	0.96*full weight	gain*0.96
42*	Temperature effect	Tabular values	Graphical function
43	Lower critical temp	39-(IN*(HE)*.85)	39-(IN*(HE)*.85)
44	Heat production	(MEI-(RE+YEn+NEpreg))/SA	if(REB=0)THEN(0)ELSE((MEI-(REB))/SA)
45*	Metabolizable energy intake	0.001*TDNAPP*4.409*.82	TDN*4.409*.82*.001

* Equations are applicable to all animal production stages.

Table 9. Model development equations for the yearling component based on NRC (1996).

Number	Variable name	NRC (1996)	Stella code
46	Dry matter intake	(SBW$^{0.75}$*(0.2345 NE_{ma}-0.0466 NE_{ma}^{2}-0.0869))/NE_{ma})((BFAF)(BI)(ADTV) (TEMP1)(MUD1)	if(NEma<=1)then((((SBWhe^.75*((0.2435*.95)-0.0466*(.95^2)-0.0869))*((.97*1.04*1*temp1)))))else((((SBWhe^.75*((0.2435*NEma)-0.0466*(NEma^2)-0.0869)*((.97*1.04*1*temp1))))))
47	Net energy for pasture activity	((0.006*pl*(0.9-(TDNp/100)))+(0.05*terrain/(pavail+3)))*BW/4.184	IF(pastI<=0)then(0)else((((.006*(pastI)*(0.9-(TDN/100)))+(0.05*1.5/((pAvailHE)+3))*(Heifer_wt/4.184)))
48	Net energy required for maintenance	[(0.077 SBW$^{0.75}$(BE)(L)(sex)(0.8+((CS-1)*0.05)] + ((0.0007)(20-Tp))	0.077*(SBWhe^.75*(0.8+((CS_He-1)*0.05))+0.0007*(20-Actual_Temp))
49	Condition score	input value	5+((Heifer_wt-Initail_Heifer)/50)
50	Surface area	0.09*SBW$^{0.67}$	.09*SBW ^0.67
51	Cold stress	SA(LCT-Tc)/IN	SA_HE*(LCT_HE-Actual_Temp/IN_HE)
52*	Me efficiency(km)	diet NE_{ma}/ME	IF(ME_in=0)THEN(0)ELSE(NEma/ME_in)
53	Lower critical temperature	(39-(IN*(HE)*.85)	(39-(IN_HE*(HE_HE)*.85))
54	Shrunk weight gain	13.91 RE $^{0.9116}$EQSBW$^{-0.6837}$	if(RE_HE<=0)then(0)else(13.91*(RE_HE^.9116)*(Eqsbw_HE^-0.6837))
55	Tissue insulation	5.1875+(0.3125*CS)	5.1875+(0.3125*CS_He)
56	Total insulation	TI+EI	EI_HE+TI_HE
57	External insulation	(7.36-0.296Wind+2.55Hair)*Mud2*hide	((7.36-(.296*5)+ (.55*2.55)*.2))

Table 9. Continued

Number	Variable name	NRC (1996)	Stella code
58	Intake for maintenance	$(NE_m + NE_{mact})/(NE_{ma}*ADTV)$	(if(NEma<=1)then(NEmHE+NEpastHE/.95)else((NEmHE+NEpastHE)/NEma))
59	Retained energy	$(DMI-Im)*NE_{ga}$	(if (NEga<=0) then (0)else((DMI_HE-ImHE)*NEga))
60	Heat production	(MEI-(RE+Yen+NEpreg))/SA	(MEI_2-(RE_HE))/SA_HE
61	Equivalent shrunk body weight	SBW*(SRW)/FSBW	SBWhe*(SRW_HE/Fsbw_he)
62	Shrunk body weight	Full weight * 0.96	Heifer_wt*.96
63	Pasture available to animal	input	if(DMI_HE<=0)then(0)else(DMI_HE*Graze)
64	Weight gain	SBW	SBW_HE

*Applicable to all animals at all production stages

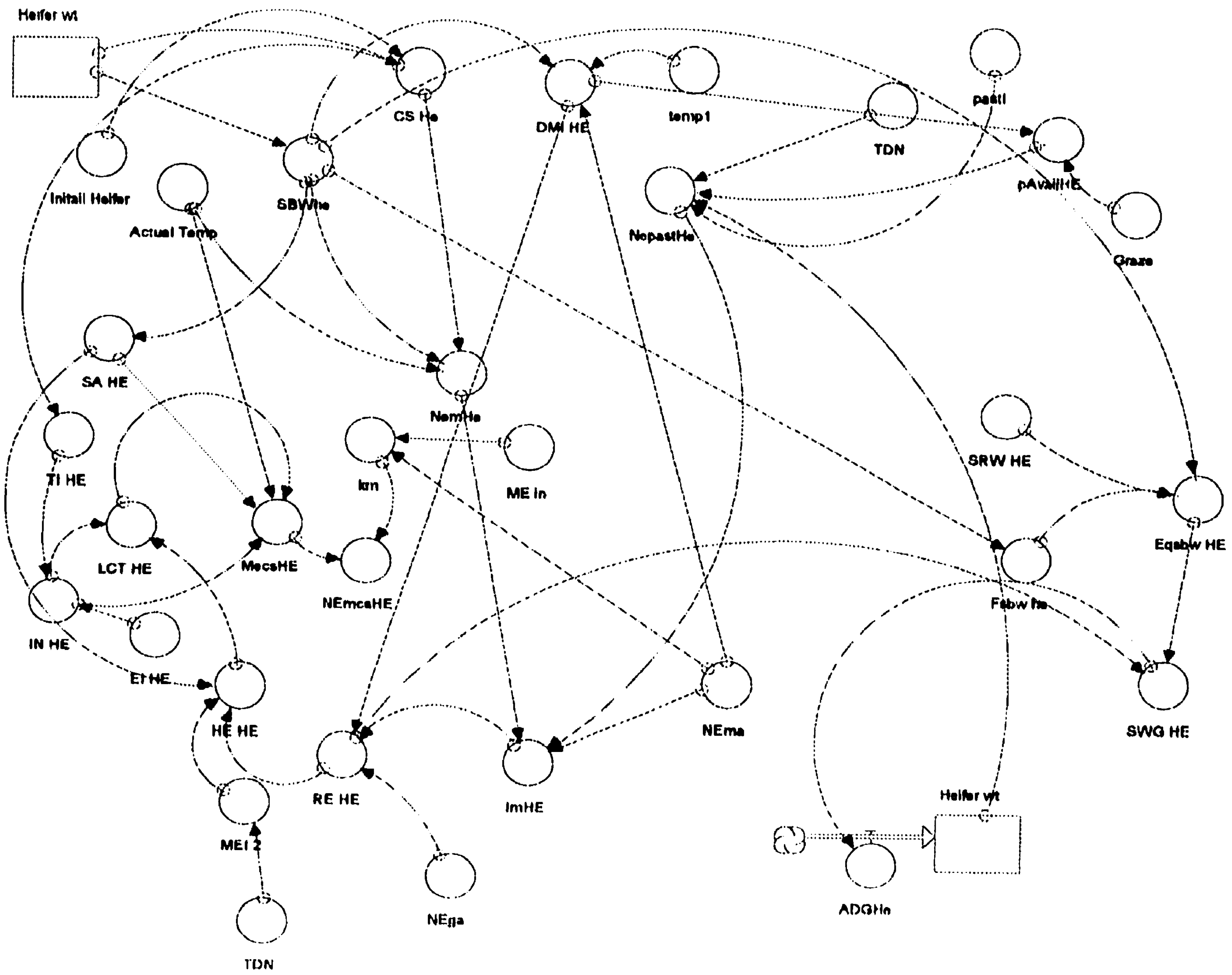

Figure 5. Yearling component as it appears in Stella 5.1 (HPS, 1998).

Table 10. Model development equations for the calf component based on NRC (1996) .

Number	Variable name	NRC (1996)	Stella code
65	Dry matter intake	$(SBW^{0.75}*(0.2435NE_{ma}-0.0466*NE_{ma}^{2}-0.1128))/NE_{ma})(BFAF)(BI)(ADTV)(TEMP1)(MUD1)$	(if(SBWca<200)then(SBWca^.75*((0.2435*NEMAC)-0.0466*(NEMAC^2)-0.1128))*((.97*1.04*1*temp1))))else(if(NEma<=1)then(((SBWca^.75*((0.2435*.95)-0.0466*(.95^2)-0.0869))*((.97*1.04*1*temp1)))else(((SBWca^.75*((0.2435*NEma)-0.0466*(NEma^2)-0.0869))*((.97*1.04*1*temp1))))))
66	Net energy available of maintenance	((1.37*MilkME-0.138*MilkME^2 +0.0105*MilkME^3-1.12))	((1.37*YEN-0.138*YEN^2+0.0105*YEN^3-1.12))
67	Net energy available for gain	(((1.42*MilkME-0.174*MilkME^2 +0.0122*MilkME^3-1.65)))	(((1.42*YEN-0.174*YEN^2+0.0122*YEN^3-1.65)))
68	Condition score	input value	5+((calf_wt-Initial_Calf)/50)
69	Energy requirements for maintenance	$(0.077*[(SBW^{0.75}(BE)(L)(Sex)(0.8+((CS-1)*0.05)]+0.0007(20-Tp))$	0.077*(SBWca^.75*(0.8+((CS_ca-1)*0.05)+0.0007*(20-Actual_Temp)))
70	Energy requirements for pasture activity	(.006*(pl)*(0.9-(TDNp/100)))+(0.05*1.5/((pavail)+3)*(BW/4.184)))))	IF(pastl<=0)then(0)else((((.006*(pastl)*(0.9-(TDN/100)))+(0.05*1.5/((PavailCA)+3)*(calf_wt/4.184))))
71	Intake required for maintenance	$(NE_{m}+NE_{mact})/(NE_{ma}*ADTV)$	if(NEma<1)then((NEm_Calf+NEpastc)/.95)else((NEm_Calf+NEpastc)/NEma)
72	Cold stress	SA(LCT-Tc)/IN	SA_CA*(LCT_CA-Actual_Temp/IN_CA)
73	Surface area	$0.09*SBW^{0.67}$	0.09*(SBWca^.67)

Table 10. Continued

Number	Variable name	NRC (1996)	Stella code
74	Insulation	TI+EI	TI_ca+EI_CA
75	Tissue insulation	2.5(newborn), 6.5 (1month +)	IF(Calf_Age<=30)then(2.5)else(6.5)
76	External insualtion	(7.36-0.296Wind+2.55Hair) *Mud2*hide	((7.36-(.296*5)+ (.55*2.55)*.2))
77	Retained energy	(DMI-Im)*NE_{ga}	if((sbwca<=200))then((DMI_CA-IM_Ca)*NEGC)else(if (NEga<=0) then (0)else((DMI_CA-IM_Ca)*NEga))
78	Equivalent shrunk body weight	SBW*(SRW)/(FSBW)	SBWca*(SRW_CA/FSBW_CA)
79	Shrunk weight gain	13.91*$RE^{0.9116}$ *$EQSBW^{-0.6837}$	if(RE<=0)then(0)else(13.91*(RE^.9116)*(EQSBW_CA^-0.6837))
80	Weight gain	SWG	SWG
81	Lower critical temperature	39-(IN*(HE)*.85)	39-(IN_CA*(He_CA)*.85)
82	Heat production	(MEI-(RE+YEn+NEpreg))/SA	(MEI_2-(RE))/SA_CA

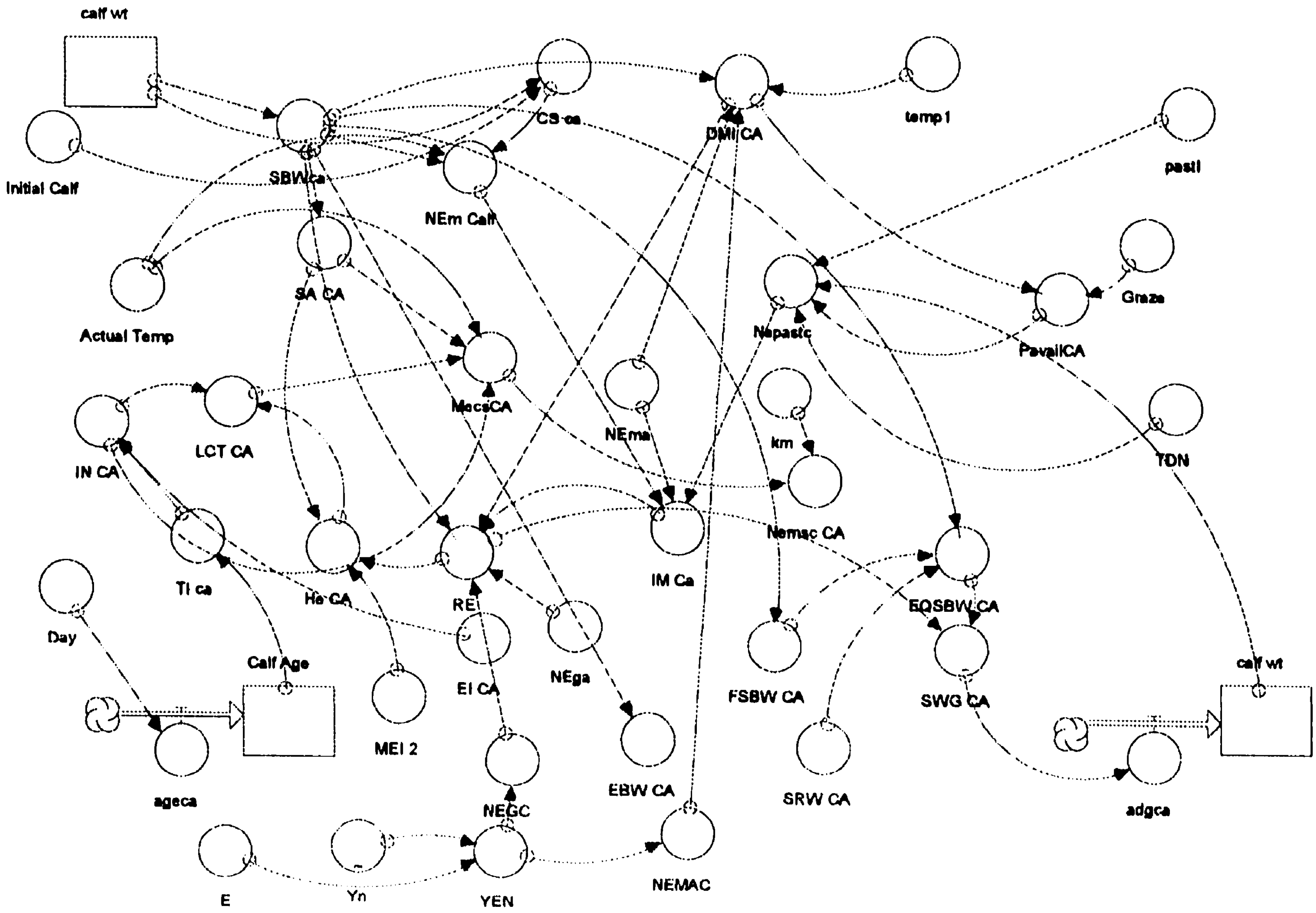

Figure 6. Calf component as it appears in Stella 5.1 (HPS,1998).

Table 11. Model development equations for the pregnant cow component based on NRC (1996).

Number	Variable name	NRC (1996)	Stella code
83	Dry matter intake	$((SBW^{0.75}8(0.04997\ NE_{ma}^{2}-0.0869))/NE_{ma})(TEMP1)(MUD1)+0.2Yn)$	(if(NEma<=1)then(if(preg<=94)then(((SBW_2^0.75)*(0.04997*.95^2+0.03840)/.95)*temp1*MUD_2+1.4))else((((SBW_2^.75)*((0.04997*.95^2+0.04361)/.95)*temp1*MUD_2+(0.2*Yn))))else(IF(Pregday<=94)THEN((((SBW_2^0.75)*(0.04997*NEma^2+0.03840)/NEma)*temp1*MUD_2+1.4))else(((((SBW_2^.75)*(0.04997*NEma^2+0.04361)/NEma)*temp1*MUD_2+(0.2*Yn)))))
84	Condition score	input value	5+((Preggain-Initial_Wieght)/50)
85	Net energy requirements for maintenance	$[(0.077\ SBW^{0.75}(BE)(L)(sex)(0.8+((CS-1)*0.05)]+((0.0007)(20-Tp))$	((0.077*(SBW_2^.75)*1*1.2*(.8+((CSpreg-1)*.05))+(.0007)*(20-Actual_Temp)))
86	Net energy required for activity on pasture	$((0.006*pl*(0.9-(TDNp/100)))+(0.05*terrain/(pavail+3)))*BW/4.184$	IF(pAvailP <= 0)then(0)else((((.006*(pastI)*(0.9-(TDN/100)))+(0.05*1.5/((pAvailP)+3)*(Preggain/4.184)))))
87	Intake required for maintenance	$(NE_{m}+NE_{mact})/(NE_{ma}*ADTV)$	if(NEma<=1)then((NEm_reqt_2+NEmactpr+NE_Mpreg)/.95)else((NEm_reqt_2+NEmactpr+NE_Mpreg)/NEma)
88	Cold stress	SA(LCT-Tc)/IN	SA_2*(LCT_2-Actual_Temp/IN_2)
89	Surface area	$0.09*SBW^{0.67}$	0.09*SBW_2^.67
90	Insulation	TI+EI	((7.36-(.296*5)+ (.55*2.55)*(CSpreg*.75)*.2))
91	Retained energy	$(DMI-Im)*NE_{ga}$	(if(DMI_Preg=0)THEN(0)else((DMI_Preg-IM3_2)*NEga)or(if (NEga=0) then (0)else(DMI_Preg-IM3_2)*NEga))

Table 11. Continued

Number	Variable name	NRC (1996)	Stella code
92	Equivalent shrunk body weight	SBW*(SRW)/(FSBW)	(SBW_2*(SRW_2/FSBW_2))
93	Shrunk weight gain	$13.91*RE^{0.9116}*EQSBW^{-0.6837}$	(13.91*(REB_2^.9116)*EQSBW_2^-0.6837)
94	Lower critical temperature	39-(IN*(HE)*.85)	39-(IN_2*(HE_2)*.85)
95	Heat production	(MEI-(RE+YEn=NEpreg))/SA	(MEI_3-(REB_2))/SA_2
96	Weight gain	SWG+fetal growth	SWG_2+baby
97	Weight lose	Fetal growth	if(twoday=377)then(babywt)else(0)
98	Fetal growth	$CBW*(0.3656-0.000523t)*e^{((0.0200*t)-(0.000143*t^2))}$	if((Pregday<=95))then(0)else(if(twoday=378)then((CBW*(0.3656-(0.000523*init(Pregday)))*EXP(((0.0200*init(Pregday))-0.000143*init(Pregday)^2)))else(CBW*(0.3656-(0.000523*Pregday))*EXP(((0.0200*Pregday)-0.000143*Pregday^2))))
99	Conceptus weight	$(CBW*0.01828)*e^{((0.0200*t)-(0.000143*t^2))}$	if(Pregday<=95)then(0)else((CBW*0.01828)*EXP((0.0200*Pregday)-(0.000143*Pregday^2))/1000)
100	Shrunk body weight	Full weight * 0.96	Preggain*0.96
101	Net energy required for pregnancy	$CBW*(Km/0.13)*(0.4504-0.0000996t)\ e^{((0.03233-0.0000275t)t)}$	(CBW*(km/0.13)*(0.4504-0.0000996*pregday)*exp(((0.03233-0.0000275*pregday)pregday))

Table 12. Constant and initial values used in the animal component.

Variable name	Abbreviation	Equation number(s)	Value	units
Standard reference weight	SRW	33,61,78,92	478	kg
Breed effect	BE	22,48,69,85	1	-
Breed adjustment	BI	18,46,65,83	1.04	-
Mud factor 1	MUD1	18,46,65,83	0.85	-
Body fat adjustment	BFAF	18,46,65,83	0.97	-
Calf birth weight	CBW	101, 99, 98	36	kg
Mud factor 2	MUD2	22, 48, 69, 85	0.8	-
Wind factor	WIND	22, 48, 69, 85	5	km/hour
Hair factor	HAIR	22, 48, 69, 85	5	cm
Hide factor	HIDE	22, 48, 69, 85	2	-
Yearling initial weight	Heifer Weight	41	250	kg
Lactating cow initial weight	Gain	41	300	kg
Pregnant cow initial weight	Pregain	41	350	kg

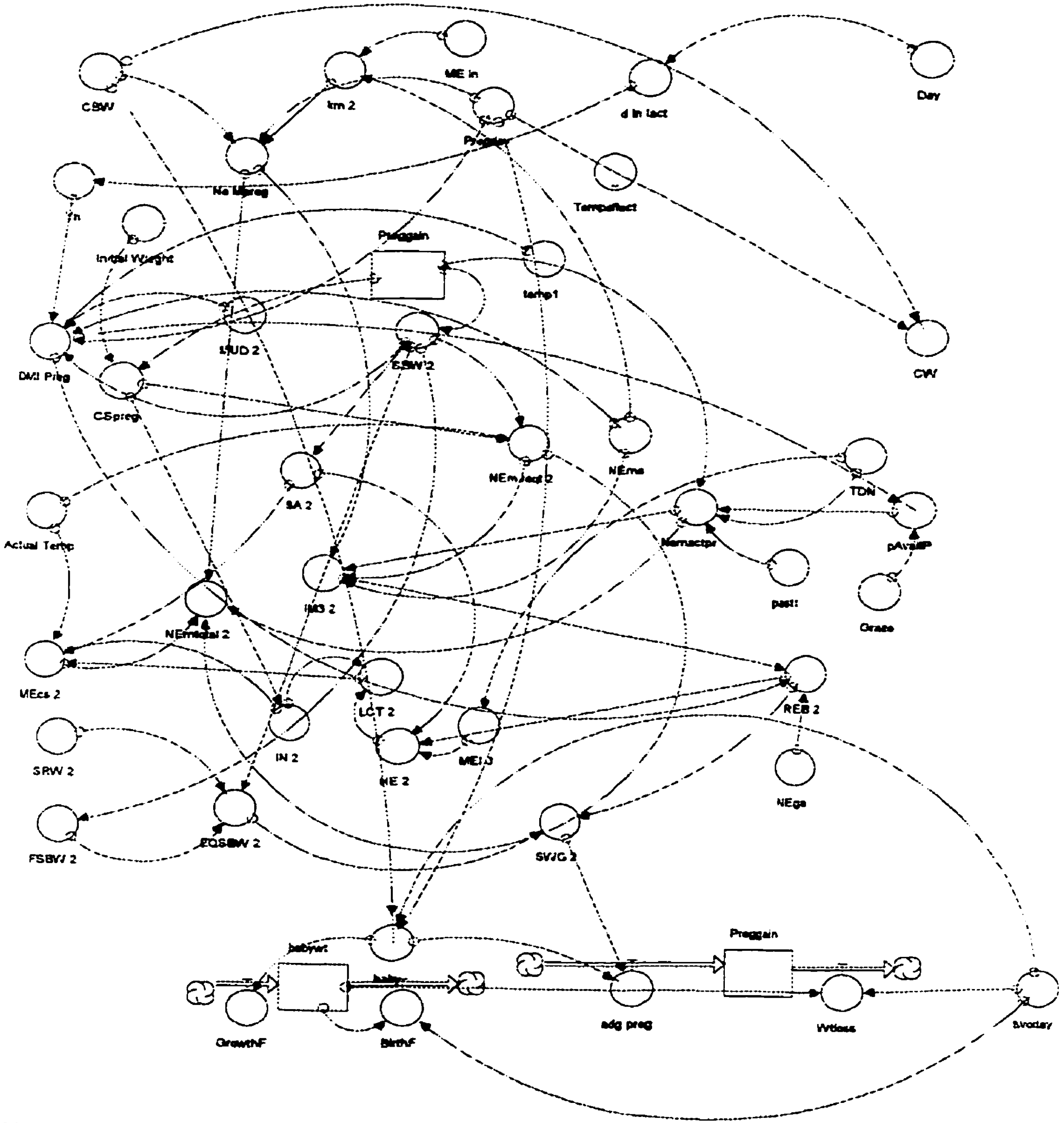

Figure 7. Pregnant cow component as it appears in Stella 5.1 (HPS, 1998).

2.5.4 Weather Component

The weather component used in the simulated system was developed by Duynisveld, (1996). The CCN for Truro, Nova Scotia were used to predict weather occurrences. The weather component was represented by convertors and a graphical function (Figure 9). When translating into the Stella 5.1 (HPS, 1998) code (Table 13), graphical functions were used to simulate rainfall, solar radiation, potential evapotranspiration, and minimum, maximum, and average temperatures (Appendix D).

Table 13. Weather component equations and corresponding Stella 5.1 (HPS, 1998) code.

Number	Variable name	Stella Code
102	Average rainfall	Graphical function (Appendix D)
103	Actual rain amount	`IF(Rain_ran=1)then(ABS(NORMAL(Rain/(POP),RainD,546))*2)else(0)`
104	Random rainfall	`MONTECARLO(POP,75)`
105	Possibility of rain	Graphical function (Appendix D)
106	Standard deviation rain	Graphical function
107	Solar radiation	Graphical function (Appendix D)
108	Potential evapotranspiration	`If((-87.03+(0.928*(Max_Temp*(1/.5555)+32))+(0.933*(ABS((Max_Temp-Min_Temp))*(1/.5555)+32))+((Solar_Radiation*.00203)))<0)then(1)Else((-87.03+(0.928*(Max_Temp*(1/.5555)+32))+(0.933*(ABS((Max_Temp-Min_Temp))*(1/.5555)+32))+((Solar_Radiation*.00203))))`
109	Maximum temperature	Graphical function
110	Minimum temperature	Graphical function
111	Actual temperature	`NORMAL(Temp_2,TempD,90){C}` (Appendix D)
112	Standard deviation temperature	Graphical function
113	Average temperature	Graphical function

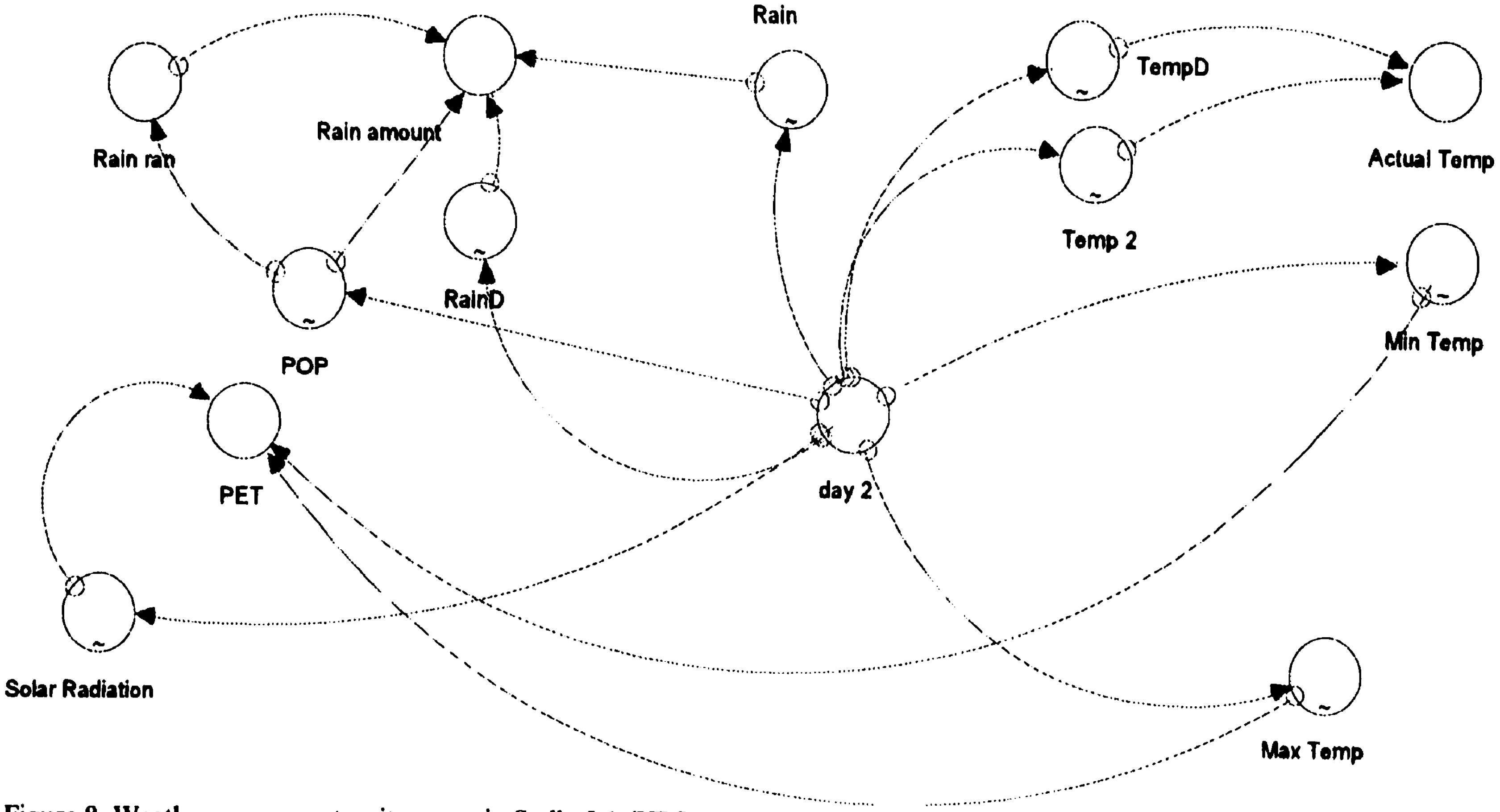

Figure 8. Weather component as it appear in Stella 5.1 (HPS, 1998).

To simulate a random event, the Monte Carlo built-in function was used to produce random zeroes and ones for a given probability. These values were then used to satisfy the condition for actual rainfall (103). If the random rainfall (104) variable produced a 1 then rainfall would occur in the simulation. The rainfall amount is calculated by a NORMAL function. This function used the standard deviation of rainfall amounts and the average on a daily basis to generate a series of rainfall amounts in a typical distribution pattern over the year. The same setup was used to simulate the daily temperatures (111). The equation for potential evapotranspiration was based on the equation developed by Baier and Robertson (1965), which uses daily temperatures and solar radiation to calculate the evapotranspiration.

The APBM used the Monte Carlo function in Stella 5.1 (HPS, 1998) to simulate random weather events over two years. It is important to note that when using this type of function, running the simulation a large number of times is required to obtain average values for the weather variables (Manly, 1993; Bailey, 1967). For example, to obtain average rainfall values using the Monte Carlo function, at a 0.05 confidence level, it should be simulated 1000 times (Manly, 1993).

The weather output by the Monte Carlo function used for the APBM predicted results for both rain and temperature values that were typical of the Truro area. However, if the APBM is to be used in future research which requires prediction of average weather conditions over a longer period of time, it is recommended that the procedure described above be used for more representative weather conditions. Perhaps more simplistically, an empirically generated average curve representing the Truro weather conditions would be the most effective .

2.5.5 Overall System

The APBM system combined the weather, animal, and plant components to simulate production over 2 years. The plant component utilized the temperature, solar radiation, and rainfall amount to simulate ME. The animal component utilized the plant ME to simulate growth and production. The weather component also affected the animal through temperature effects on NE requirements. Due to the complexity and lack of detailed knowledge of the animal effect on plant growth, this aspect was not simulated by this model.

Chapter 3:

Model Refinement and Behaviour

3.1 Introduction

In simulation modelling, it is important to be able to assess how precisely and accurately the model is predicting (Csaki, 1985; France and Thornely, 1985). Before a model can be used to evaluate different management scenarios, the user must have a degree of confidence in the model's ability to reflect reality. The APBM system was evaluated using the approach suggested by Vanclay and Skovsgaard (1997). The procedure involves verifying the model's behaviour, observing its sensitivity to changes in selected parameters and calibration procedures.

3.2 Model Verification

3.2.1 Introduction

Once constructed, it was important to test the model behaviour. Model output was graphed to evaluate if it was, in a general sense, describing the biological functions it was intended to represent. This was accomplished by employing two methods: 1) Model output was compared to the theoretical behaviour documented in textbooks and previous research, and 2) The model generated output was compared graphically to the data collected for calibration and validation.

3.2.2 Plant Component

Forage quality in terms of ME decreases as the plant ages and develops. When the model output of ME was compared with the theoretical behaviour of ME the predicted values showed a similar trend to the observed data(Figure 9). The model output showed a general decline in ME over time.

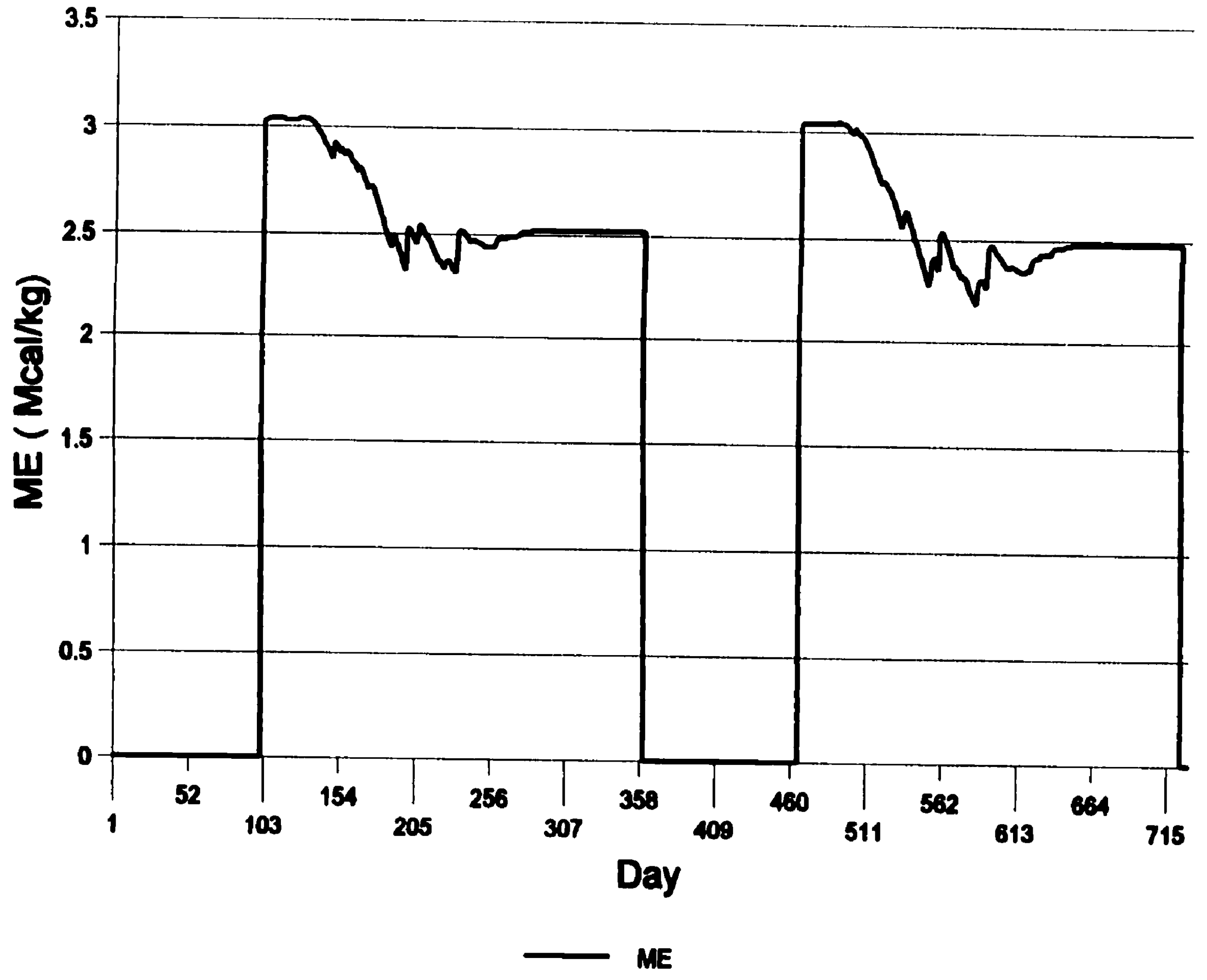

Figure 9. Model output of ME over two year period.

The ME was the variable of interest, but biomass output was also examined to ensure that biomass prediction was functioning correctly (Appendix E).

The change in ME over time predicted by the model was graphed along with the calibration and validation data (Figure 10). The graph indicated a similar pattern of behaviour between the observed and predicted curves. Generally, when the observed data peaked, so did the output data.

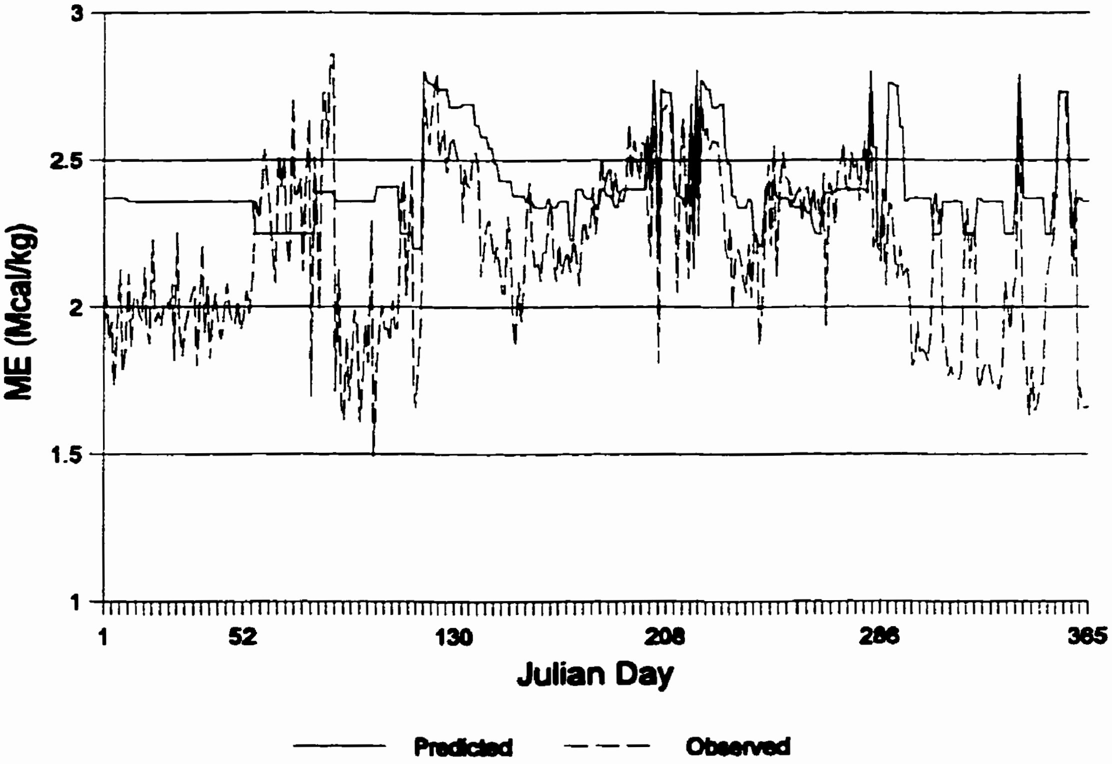

Figure 10. Observed ME and predicted ME(Mcal/kg) in pasture over time.

3.2.3 Animal Component

The animal growth component was based on the Gompertz equation (Taylor, 1968). This equation predicts exponential growth and actual weight gains of animals. There appeared to be a close relationship between the predicted animal growth curves and an exponential growth curve (Figure 11).

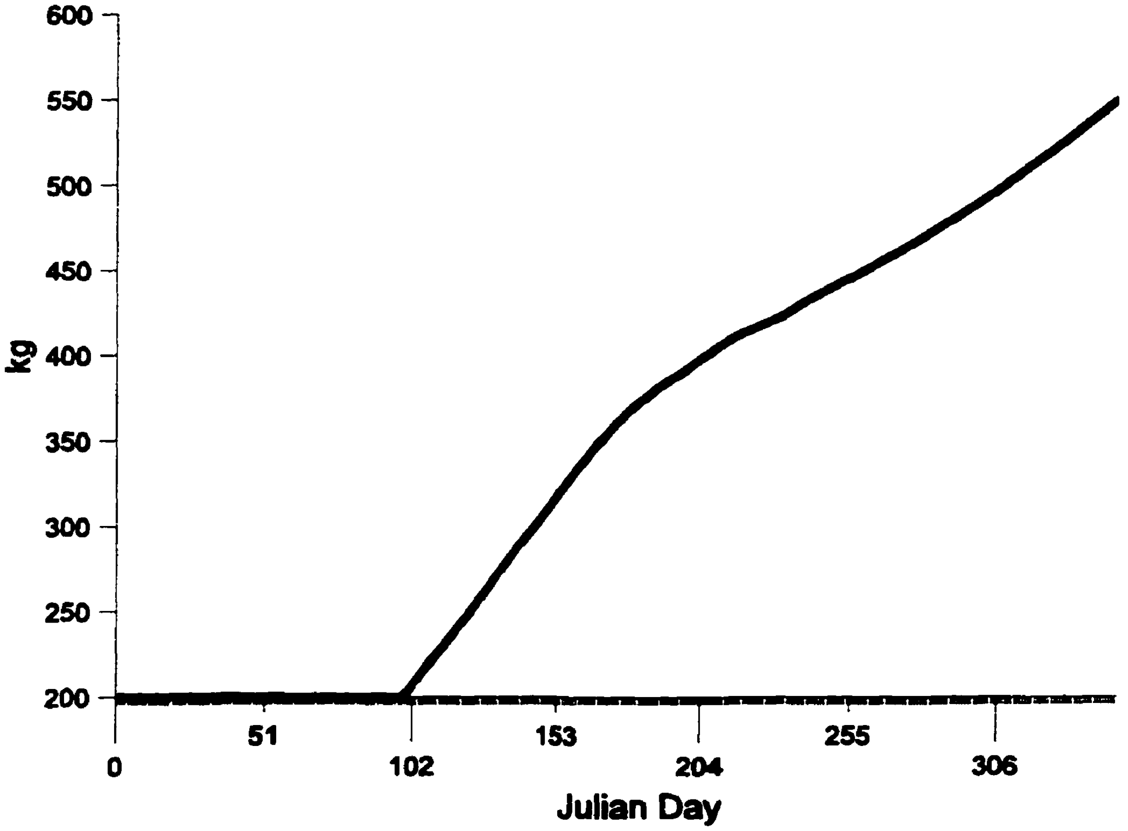

Figure 11. Typical model output of weight gain(kg) in beef animals.

The model predicted weight gains resembled the observed data for all production stages (Figure 12).

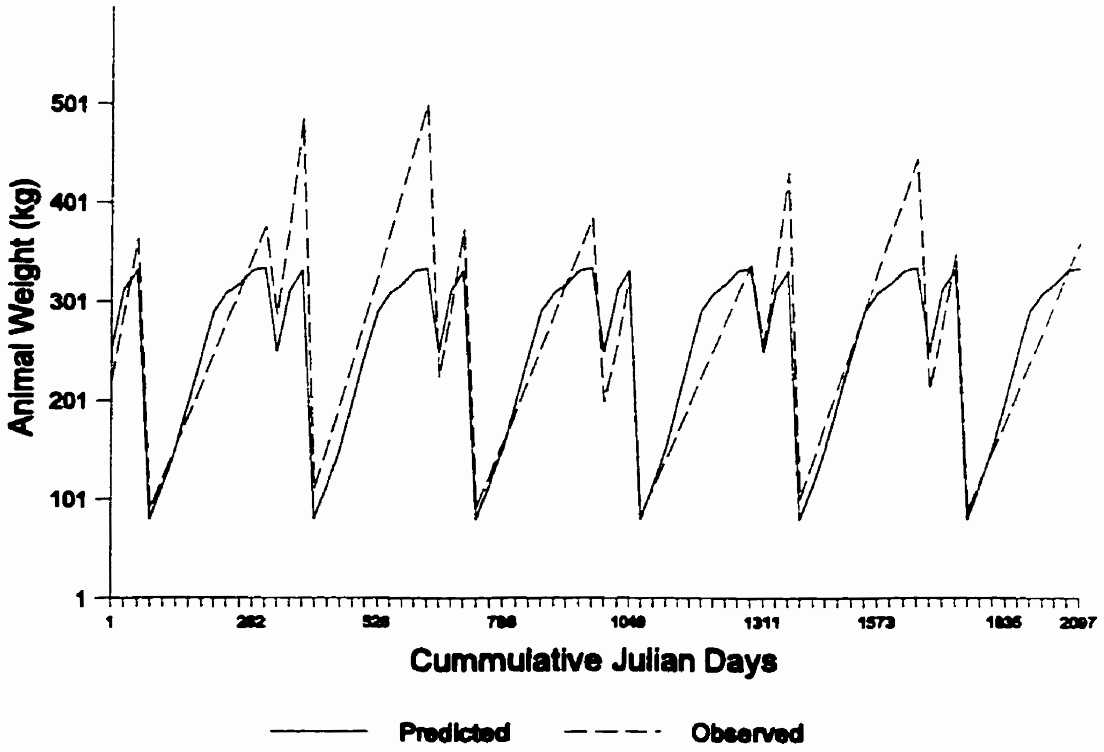

Figure 12. Observed and predicted animal weight gain (kg) over time.

3.2.4 Overall System

When the models were coupled, the output was examined for inconsistent behaviour. None was detected. The curve of the ME intake followed that of the DMI (Figure 13).

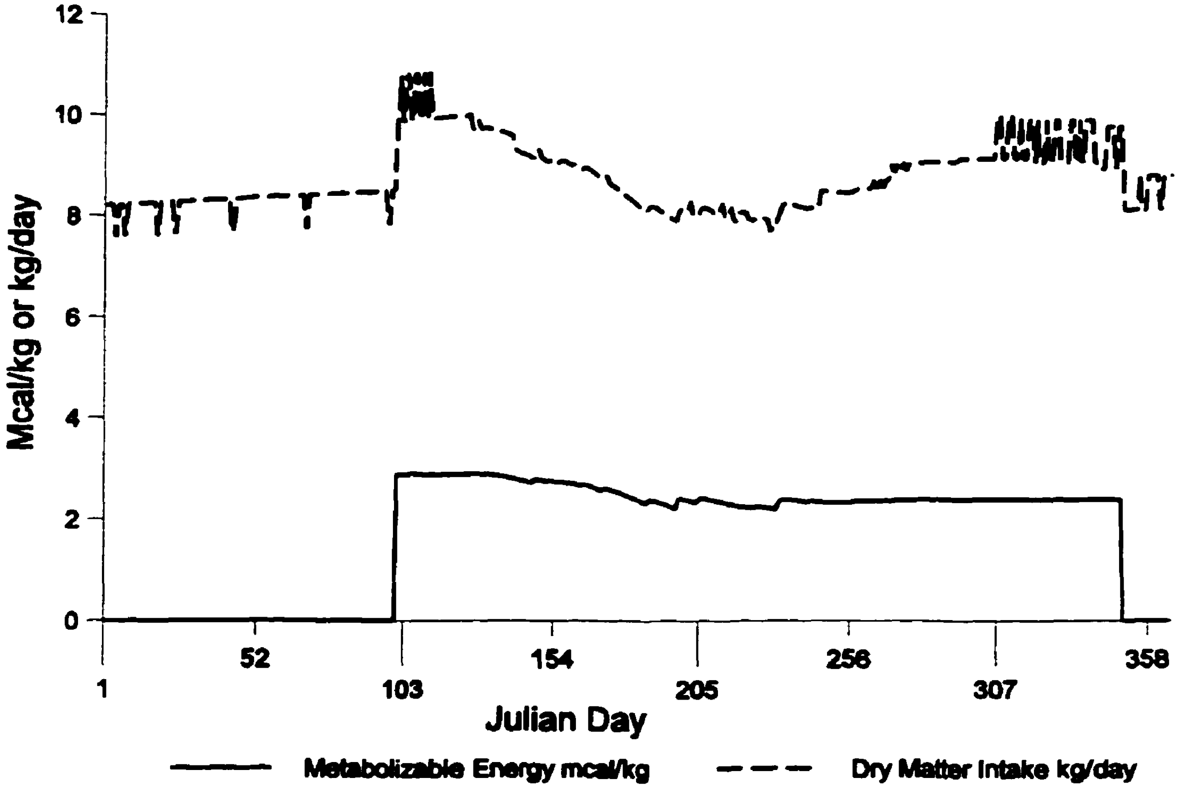

Figure 13. Model output of ME(Mcal) and dry matter intake (kg/day) over time.

3.3 Model Sensitivity

3.3.1 Introduction

The sensitivity analysis was accomplished by varying several parameters (one at a time) by known incremental amounts, and observing the effects on model output.

3.3.2 Plant Component

The output of interest for the plant component was the plant ME production. The critical parameters involved in ME production were: critical photoperiod, base temperature, and the coefficient used to simulate non-digestible organic matter accumulation (OMPAR). Each of these parameters was either increased or reduced by increments of 30% and 50%, then the effects on ME were observed (Table 14).

Table 14. Critical parameters were modified to assess the sensitivity of ME output in terms of percent change.

Parameter	-50%	-30%	30%	50%
Photoperiod	-15.0	-8.1	15.0	15.0
Temperature	-8.7	-5.5	5.5	8.7
OMPAR	-5.3	-3.2	3.9	6.2

Change in photoperiod had the greatest affect on ME output. When the critical photoperiod (14 hours) was reduced by 30% (from 14 hours to 9.8 hours), and 50% (from 14 hours to 7 hours), ME values were reduced by approximately 8.1% and 15%, respectively. When critical photoperiod was increased by 30% (from 14 hours to 18.2 hours), and 50% (from 14 hours to 21 hours), ME increased by 15% for increments tested.

The ME output was reduced when the value of critical photoperiod was reduced and ME increased when the critical photoperiod was increased. This result is due to the structure of the phasic development equation for the plant. The minimum photoperiod required for development (critical photoperiod) was set at 14 hours. If the number of hours of solar radiation (photoperiod) exceeded this value, the plant would develop. Therefore, a lower value for critical photoperiod would cause the plant to develop more quickly than a higher value critical photoperiod. In effect, it would increase biomass accumulation and consequently decrease ME production of the plant.

The ME output was less sensitive to critical temperature than it was to photoperiod. When the critical temperature (5° C) was changed by 30% (increased to 6.5°

C and reduced to 3.5° C, respectively), the ME output altered by ± 5.5 % respectively. Likewise, when the temperature was altered by ±50% (7.5° C and 2.5° C) the ME output was modified by ● 8.7% respectively. The critical temperature affected the phasic development equation in a similar way as the photoperiod. A reduction in critical temperature indirectly caused a reduction in ME output by increasing the rate of biomass accumulation.

Finally, the sensitivity of ME was tested using the parameter used to describe the rate of accumulation of non-digestible organic matter. These results indicated that when compared to the critical photoperiod and the base temperature, ME was the least sensitive to variations in the OMPAR value. When the original value of OMPAR (1.69) was reduced by 30% (OMPAR=1.183) and 50% (OMPAR=0.845), the ME was reduced by 3.23% and 5.3%, respectively. When the OMPAR was increased by 30% (OMPAR=2.197) and 50% (OMPAR=2.535), the ME value increased by 3.9% and 6.2%, respectively. The rate of non-digestible organic matter had a more direct effect on ME than the other two parameters in the model tested for sensitivity. However, it had the least effect on the output of the model.

Overall, the critical photoperiod had the greatest effect, temperature had a lesser effect and OMPAR had the least effect on plant ME output. From these results, it appeared that the values chosen for the photoperiod and temperature parameters were paramount for accurately predicting the plant component.

3.3.3 Animal Component Sensitivity

For this research, animal weight gain was identified as the animal output of interest. Values of the parameters mud and the standard reference weight were changed ±30% and ±50% to examine the effects on animal weight gain respectively. The sensitivity results reported here are the average values for all the animal stages. The values used for this sensitivity analysis were the same for all production stages due to the fact that the equations were all similarly structured.

The sensitivity of animal weight gain to the mud effect on animal weight was observed (Table 15). The original mud value (0.85)was used in model construction. Animal weight gain was sensitive to increases and reductions of 30% and 50% in the mud value. For a 50% reduction (mud=0.425), animal weight gain decreased by 34% and a 30% reduction (mud=0.595) resulted in a 23% reduction in animal weight gain. When the same parameter was increased by 30% (mud=1.105) the overall gain increased by 25%, and when mud was increased to 1.275 (50% higher), animal gain increased by 43%.

The sensitivity of animal gain to the standard reference weight was observed (Table 15). Standard reference weight had the largest effect on weight gain when it was decreased by 30% and by 50% (20.8% and 50% decrease respectively). When increased, standard reference weight showed a percentage change in overall weight gain that was considerably less than when it was decreased(11% for a 30% increase and 15.8% for 50% increase).

Table 15. Parameters varied for sensitivity analysis and the percent change in animal gain.

Parameter	-50%	-30%	30%	50%
Mud	-34	-23.2	25	43.3
Standard Reference Weight	-50	-20.8	11	15.8

Both standard reference weight and the mud factor directly affected the average daily gain equations for all animal production stages. Daily weight gain was calculated using the retained energy value and the equivalent shrunken body weight. The mud factor directly effects the energy taken in by the animal and also the amount of energy available for weight gain and body maintenance. To determine weight gain the energy requirements were subtracted from the amount of energy provided from intake. The reference weight influenced overall weight gain in that the equivalent body weight is directly calculated from this value. The independent evaluation of the NRC (1996) model showed that standard reference weight was the variable with the largest influence on animal gain.

3.3.4 Summary

The ME output of the plant component was most sensitive to the critical photoperiod and critical temperature, and was affected less by the non-digestible organic matter accumulation factor. The animal component was largely affected by a decrease in standard reference weight, but a lesser effect was noted when the reference weight was increased. Finally, the mud parameter had a moderate effect on animal weight gain.

3.4 Model Calibration

3.4.1 Introduction

Calibration procedures involved comparing the model output to a set of observed data. To maintain the integrity of the model evaluation process it was essential to calibrate and validate each with separate sets of data. Model calibration utilized data sets collected from research trails conducted in Charlottetown, Nappan, Truro, and Fredericton .

These data represented (as closely as possible) the system being simulated and was collected from a geographical region for which the APBM was intended. The model equations were then manipulated through parameterization until the output values of the model were representative of the observed data sets. The degree of fit between the observed data and the model output was evaluated through regression analysis.

The ideal regression result, between observed and predicted values would be $y=1x+0$ (in the form of the linear equation $y=mx+b$) or essentially, $y=x$. The slope estimation (m) represented the amount of over (less than 1) or under (greater than 1) prediction by the model. A high coefficient of determination ($r^2=1$), would indicate a perfect fit when comparing observed data to predicted values. It was necessary to determine if there was a significant relationship between the observed and predicted data using the F-Test. Using the degrees of freedom associated with the explained and unexplained variation, a significant relationship between the two sets of data was determined from the F value given in regression analysis compared to a tabular F-statistic (Hoshmand, 1988). All regression analyses were completed using Minitab 12 (Minitab Inc, 1998).

3.4.2 Plant Component Calibration

The ME production in pasture plants change according to the stage of plant development and plant species. This research investigated pasture type in combination with calving management. There are two basic types of pastures in Atlantic Canada: 1) Naturalized (not seeded in the past 20 years), and 2) Seeded (has been seeded with species improved for energy content and biomass accumulation). From the data collected there were three categories: 1)Overall pasture (a pasture not classified by plant species)

2) Seeded, and 3)Naturalized.

The initial output of ME from the model (without calibration) gave ME values 20 times that of an average value of pasture in this region. Therefore, a conversion factor was used.

Three stages of calibration were completed (Table 16). The first calibration stage (overall pasture) was based on the conversion factor of 20. The result from this calibration stage indicated that the best fit equation was $y=1.19x+0.231$ with an $r^2=0.46$. The slope indicated that for this type of pasture, the model had under predicted ME slightly and had a moderate-to-low fit to the calibration data. However, when the model was calibrated for pasture type, the accuracy of prediction increased. For naturalized pasture, the calibrated model fit the data better with an $r^2=0.58$, but was over-predicting ME. Finally, when the model was calibrated for improved-species pastures, the model fit the data best. The equation showed almost no over or under prediction ($y=1.01x-0.059$) for ME with $r^2=0.76$. The F-test showed a significant relationship between the data sets and model output for all the calibrations.

Table 16. Plant ME (Mcal) calibration results for three pasture types.

Pasture Type	N	Equation	r^2	F	$F_{0.05}$
Overall (No pasture type separation[1])	59	$y = 1.19x + 0.231$	0.46	49.99	4.00
Naturalized Pasture Calibration	68	$y = 0.819x + 0.371$	0.58	94.99	3.98
Improved Pasture Calibration	55	$y = 1.01x - 0.059$	0.76	170	4.02

Based on the calibration results, it appears that as the pasture type became more specific, the calibration became more accurate. To account for differences in naturalized pastures (which tend to be lower in energy), and improved pastures (which are higher in energy), the conversion factors of 18.875 and 18 were the final values used for model calibration.

3.4.3 Animal Component Calibration

The NRC (1996) animal production model was calibrated based on cattle breed which was accounted for in the DMI equations. The calibration factor of 1.04 (NRC, 1996) was used for this component. The calibration factor was tested using data from pasture research trails conducted at the Nappan Experimental Farm (Table 17).

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[1] No separation refers to plant data which has not been classified by pasture type or by plant species.

Table 17. Animal gain (kg) calibration results for breed factor.

Animal	N	Equation	r^2	F	$F_{0.05}$
Yearling	95	$y = 1.09x + 33.1$	0.43	71.82	3.94
Calf	41	$y = 0.706x + 88.1$	0.47	36.64	4.08
Lactating Cow	94	$y = 0.427x + 201$	0.56	118.79	3.94

The F-test indicated that there was a significant relationship between observed and predicted data for all production stages tested (yearling, calf, and lactating cow). The equation based on yearling data had the closest predicted values to the observed data. The regression equation indicated ($y = 1.09x + 33.1$) that the model was slightly under-predicting weight gain of the yearling. However, the relationship for this production stage had the lowest r^2 value (0.43). The calf and lactating cow equations over- predicted weight gain ($y = 0.706x + 88.1$ and $y = 0.427x + 201$, respectively). A moderate amount of the variation in the data was explained by the model for the calf and lactating cow (0.47 and 0.56, respectively).

Chapter 4:

Model Performance Evaluation.

4.1 Introduction

The success of a model is determined, in part, by its performance in comparison with observed data from the actual system it was intended to represent. The performance of the APBM was evaluated based on validation results and results of simulated management scenarios.

4.2 Model Validation

4.2.1 Introduction

A traditional quantitative method employed for this type of evaluation followed the regression method outlined by Vanclay and Skovsgaard (1997). The procedure involved comparing observed data (completely separate from data used for calibration) collected from on-farm research trials for the validation of individual components and validation of the overall model with data from cooperating farms.

4.2.2 Plant Component Validation

The plant component was validated in terms of ME. It was necessary to conduct validation in several stages because of the different pasture types of interest. The first stage of validation involved comparing observed data with the model output when it was calibrated for a pasture of no specific type (Table 18).

At the first validation stage, the plant ME prediction accounted for 19 % (r^2=0.19) of the variation in the observed data. The best fit equation ($y = 0.196x + 1.97$) indicated that ME was over-predicted . The F-test indicated that there was a significant relationship between observed and predicted data.

Table 18. Plant validation results separated into pasture types - no calibration.

	N	Equation	r^2	F	$F_{0.05}$
Overall (No pasture type separation[2])	207	$y = 0.196x + 1.97$	0.19	119.47	3.89
Naturalized pasture (no calibration)	163	$y = 0.461x + 1.37$	0.38	100.57	3.91
Improved pasture (no calibration)	44	$y = 0.863x + 0.299$	0.51	64.5	4.06

In an attempt to isolate the source of variation, the validation data used for the first stage(overall) was divided in two categories: 1)Naturalized pasture species, and 2) Improved pasture species. Regression analysis of observed data on predicted data was performed for each of these categories and this substantially improved model prediction (Table 18). The model accounted for a larger part of the variation when the data was separated into pasture types. The naturalized pasture ME was overestimated ($y = 0.461x + 1.37$) but a higher degree of the variation in the data seemed to be explained by the model (r^2 increased from 0.19 to 0.38). Of the validation results from the three categories, the pasture containing improved species appeared to increase the most with an r^2 value increasing from 0.19 to 0.51 and the best fit equation indicating that only a slight over-

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[2] No separation refers to plant data which has not been classified by pasture type or by plant species.

prediction of ME was occurring (y = 0.863x +0.299). A significant relationship between observed and predicted values was maintained in all categories.

The second stage of validation involved comparing the observed data to the calibrated (for naturalized and improved pastures) model output. These results showed an overall increase in model accuracy of prediction (Table 19). The calibrated model for naturalized pasture accounted for approximately half of the variation in the observed data (r^2=0.51) and the improved species model accounted for 60% (r^2=0.60) of the variation in the observed data. The ME values for both pasture types were still over-predicted (y=0.76x + 0.542 and y=0.544x +1.22, respectively).

Table 19. Plant ME(x) validation results for model calibrated for pasture type.

	N	Equation	r^2	F	$F_{0.05}$
Naturalized pasture	163	y = 0.760x +0.542	0.52	94.99	3.92
Improved pasture	44	y = 0.544x +1.22	0.60	63.59	4.06

The third and final stage of validation for the plant component separated out the individual species of pasture plants (Table 20). The 13 species identified were: birdsfoot trefoil, bluegrass, bentgrass, creeping red fescue, foxtail, late timothy, meadow brome grass, orchardgrass, smooth bromegrass, tall fescue, timothy (unknown varieties), and weeds (any plant species that was not one of the above mentioned). The results from this validation stage appeared to represent two levels of accuracy in prediction in terms of r^2; prediction at 40%(r^2=0.40) or greater and prediction at less than 40%.

The species with 40% or greater ($r^2 \geq 0.40$) of the variation in the ME data being explained by the model were: late timothy (r^2= 0.86), orchardgrass (r^2= 0.49), smooth bromegrass (r^2= 0.96), tall fescue (r^2= 0.87), and timothy (unknown varieties r^2=, 0.61). The r^2 for the other species were lower than 40%($r^2 \leq 0.40$) and included: birdsfoot trefoil (r^2= 0.11), bluegrass (r^2= 0.37), creeping red fescue (r^2= 0.27), foxtail r^2=(0.16), meadow bromegrass (r^2= 0.38), white clover (r^2= 0.04), and weeds (r^2= 0.27). The F-test confirmed that there was a significant relationship between the observed and predicted data for all species except for white clover (F=2.5, F Stat=3.98) and foxtail (F=2.7, F Stat=4.67).

Table 20. Plant ME(x) validation by species (calibrated).

Species	N	Equation	r^2	F	$F_{0.05}$
Birdsfoot trefoil	116	$y = -0.0699x + 2.48$	0.11	14.4	3.94
Bluegrass	86	$y = 0.472x+1.37$	0.37	47.1	3.96
Bentgrass	79	$y = 0.514x+1.13$	0.67	36.3	3.96
Creeping red fescue	59	$y =0.401x+1.46$	0.27	21.8	4
Foxtail	15	$y = 0.514x+1.37$	0.16	2.7	4.67
Late timothy	25	$y = -0.277x+2.78$	0.86	152.4	4.2
Meadow bromegrass	14	$y = -0.230x+2.76$	0.38	8	4.67
Orchardgrass	21	$y = 0.318x+1.76$	0.49	19.1	4.2
Smooth bromegrass	13	$y = -0.185x+2.68$	0.96	290.4	4.67
Tall fescue	11	$y =- 0.255x+2.38$	0.87	68	4.84
Timothy (unknown varieties)	45	$y = 0.538x+1.23$	0.61	68.5	4.06
White clover	67	$y = 0.120x+2.11$	0.04	2.5	3.98
Weed	21	$y = 0.408x+1.37$	0.27	7.4	2.2

4.2.3 Plant Component Performance Assessment

Thomas and Goit (1991) and Murphy (1987) state that there are two main growth patterns for pasture plants in this region: 1) unjointed stems with the growing point at the base of the plant and 2) jointed stems with the growing point at the top of the joint. The species with the best validation results of prediction (smooth bromegrass, tall fescue, late timothy, and timothy) are all tall growing grasses that have a jointed growth pattern (Nelson and Mosher, 1995). As the model was originally developed for the phasic development (growth patterns) of an unspecified variety of timothy, it is reasonable to assume that species similar to timothy would be better represented by the model.

The grasses with the r^2 values lower than 0.40 (bluegrass, bentgrass, creeping red fescue, foxtail, meadow bromegrass, and weeds) were classified as species that would most frequently occur in naturalized pastures (Butler et al. 1993). These grasses were also plants which grow low to the ground with unjointed stems and do not follow the same growth patterns as timothy.

The model explained almost none of the variation for the legumes tested here (birdsfoot trefoil and white clover). Gustavsson et al. (1995) states that the model was not suitable to represent legume growth. Plant validation results of the APBM showed similar results to the validation results of Gustavsson et al. (1995). It was found that the Gustavsson et al. (1995) model accounted for between 10-15% of the variation in the ME data. The results obtained from the APBM showed 19% of the variation in the observed ME production data was explained by the model. The low level of accuracy was possibly due to a compounding error innate in the construction of the model (Gaunt et al. 1997). An estimation of ash content in forage was directly used to estimate ME. Errors that occurred in the estimation of ash content would be carried through into the calculation of ME.

However, when the model was calibrated more specifically for pasture management type (naturalized and improved) the accuracy appeared to increase. The model's ability to predict ME of grass species similar to timothy (grass species normally associated with an improved pasture type) increased to four times that of the uncalibrated model with a range of r^2 values from 0.85-0.96. The grass species usually associated with naturalized pastures (low growing) were not represented as well by the model, but the validation results of the calibrated model still showed an improvement over the uncalibrated results.

Compared to the predictive ability of forage quality models in the past, these results indicated that the APBM was consistent with previous validation results. Fick et al. (1994) documented the history of forage quality models from the 1960s to the 1990s. None of the models documented in this review were dynamic predictors of ME. Fick et al. (1994) reviewed forage models that predict quality factors such as crude protein, acid detergent fibre, and neutral detergent fibre. These models had similar validation results to the calibrated APBM. The reported r^2 values ranged from 0.50- 0.75 for weather and age based forage predictors.

These forage quality models are, for the most part, empirical. There is a need for the development and testing of more mechanistic predictors of forage quality (Fick et al. 1994) At this point in forage quality modelling, perhaps the physical and chemical processes in plants are not yet well enough defined to model forage quality accurately. Until there are more accurate mechanistic predictors of forage quality, it may be just as successful to use generalized curves (empirical representations) to represent the change in pasture ME over time.

To assess the differences between a mechanistic ME predictor and an empirical representation of ME production, validation results of a generalized ME production curve was compared to the validation results of the Gustavsson et al. (1995) model. A generalized curve for pasture ME production over time (Figure 14) was entered into Stella

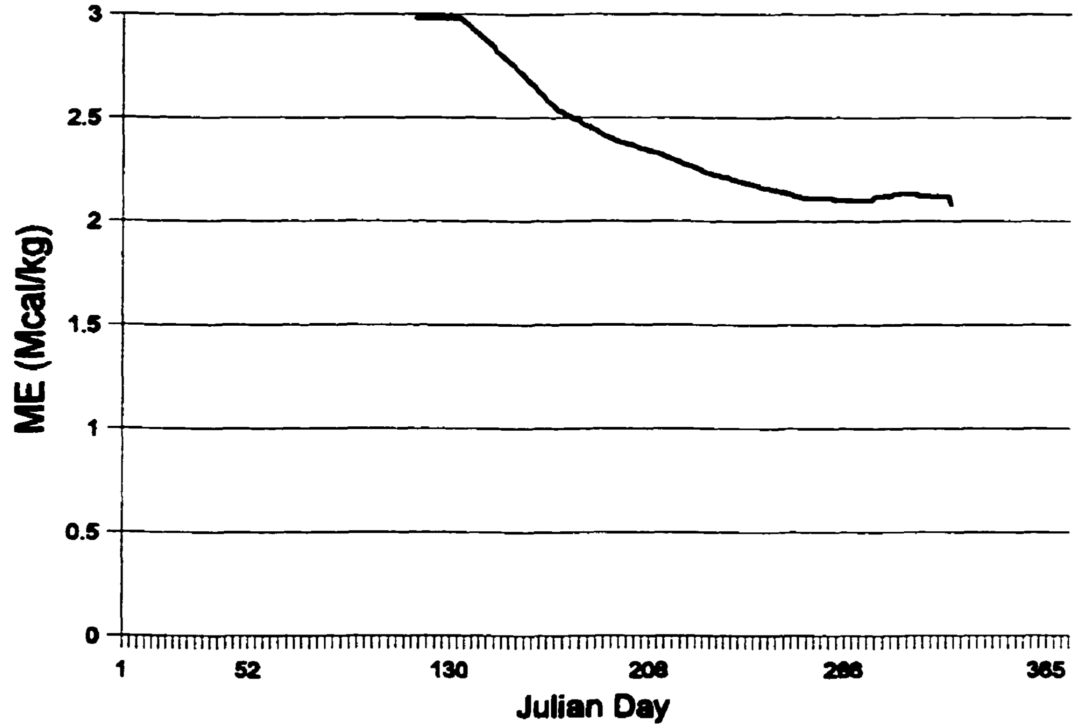

Figure 14. Generalized curve to predict ME(mcal/kg) (Gustavsson et al., 1995).

5.1 (HPS, 1998) as a graphical function, with Julian Day on the x axis and ME in Mcal/kg on the y axis. The same validation procedures as described above were used to evaluate the generalized curve. A paired t-test in Minitab 12 (Minitab Inc., 1998) was used to determine if there was any significant difference between the validation results for ME output from the mechanistic predictor and the empirical representation of ME. The validation results from the curve were compared to the individual species validation results from the calculated prediction of ME. The paired t-test indicated no significant difference between the two sets of validation results ($t = -0.5$; t test stat=1.782; $P_{0.05}=0.62$).

For the APBM, however, it was important to evaluate how each of the variables interacted with the others. The main factor that influenced plant development and ME production in this research was the weather component. The Gusstavsson et al. (1995) component model gave the APBM flexibility in terms of assessing the effects of various weather patterns.

4.2.4 Animal Component Validation

The animal weight gain was validated using data obtained from on-farm research trials throughout Atlantic Canada. The data were limited to a Hereford or Hereford cross animal. Validation was performed on three production stages of the beef animal. The validation data sets consisted of 61 yearlings, 95 calves, and 143 lactating cows, all raised in a pasture management system. Regression analysis in Minitab 12 (Minitab Inc, 1998) was performed .

The results of validation indicated that overall, the animal component predicted animal weight gain from pasture moderately well (Table 21). The F tests indicated that the relationship between observed and predicted animal data was significant for all production stages tested. The yearling appeared to have the largest amount of data variation explained by the model (r^2=0.65). The best fit equations suggested that the model was slightly under-predicting the animal weight gain for the yearling (y=1.06x +11). The calf weight gain was under-predicted by the model (y= 1.60x + 302), but about half of the variation in the observed data was explained by the model (r^2= 0.54). Finally, the lactating cow weight was slightly under-predicted (y=1.07x+94.2) whereby slightly less then 50% (r^2=0.48) of the variation of the data was explained by the model.

Table 21. Animal weight gain (kg)(x) validation results.

	N	Equation	r^2	F	$F_{0.05}$
Yearling	61	$y = 1.06x + 11.0$	0.65	110.33	4
Calf	95	$y = 1.60x + 302$	0.54	109.43	3.96
Lactating cow	143	$y = 1.07x + 94.2$	0.48	132.7	3.92

4.2.5 Animal Component Performance Assessment

Predictive models perform best when the system they are simulating have tightly controlled variables. In this research the system was pasture-based and the variables were less controllable than they would be in a feedlot production system. Cattle on pasture are exposed to variability in environmental conditions, feed availability, and foraging activity (Ward and Klopfenstein, 1991).

The NRC (1996) model used in this system attempts to simulate all the effects of these environmental variables on animal energy requirements and animal production. The NRC(1996) model has been evaluated on several levels with three individual large data sets. However, all this data was collected from feedlot operations. The NRC (1996) model was found to have accounted for 67% (r^2=0.67) of the variation in animal weight gain observed in the data sets. When results from the APBM validation were compared to those found by NRC (1996), they appeared to slightly lower accounting for ≈ 57% of the variation in animal weight gain.

Validation results from feedlot management simulations by Oltjen et al.(1986a) and the CNCPS (Fox et al . 1992) model reported higher r^2 values. Fox et al.(1998) found that the Oltjen et al. (1986a) and the CNCPS models accounted for 78% and 93% respectively, of the variation in animal weight gain. The yearling component in APBM came closest to the validation results of the NRC (1996) model. The overall average (of the three production stages) for the APBM animal component model validation results accounted for was 57% of the variation in the observed data, approximately 10 percentage points lower than the NRC (1996) model.

However, when the APBM was compared to other models that simulate pasture-based beef production systems it showed a similar level of success in prediction. The model by Fox et al. (1988) attempted to account for the effects of environmental conditions for grazing cattle and found the model accounted for 56% of the variation in the validation data.

Variation in feed composition is listed in NRC (1996) as one of the main factors contributing to the loss of accuracy in predictive ability by the model. This variation in feed composition was cited as a reason for loss in accuracy by other models as well. Typically, feedlot operations offer a more consistent feed supply of stable composition as compared to the inconsistent diet of an animal on pasture. Also, all animal energy requirements are increased when an animal is exposed to variable, uncontrollable environmental conditions such as rain, temperature extremes, wind, and varying terrain. Therefore, the lack of consistency in feed composition and uncontrollable variables add extra sources of error, thus lowering the accuracy of the model predictions (Fox et al. 1998). Finally, other sources of potential error in the validation procedure may be innate to the data. This is because data used for validation were collected for reasons other than model validation.

4.2.6 Overall Model Validation

Once the APBM coupled the animal and plant components, the output values for ME and its effects on animal weight gain were evaluated. The overall farm system was validated using data from cooperating farms. Data on forage energy content and animal gain were collected. In the validation data sets there were 25 data points for the ME, 77 data points for the yearling, and 38 data points each for the calves and lactating cows.

The plant validation results showed no change from the results of the individually validated, uncalibrated pasture model (r^2=0.18). This may be due to the fact that there were no species composition data available for the pasture.

The animal weight gain results (Table 22) showed an increase in the accountability of the model for the variation in the observed data. The relationship between observed and predicted values was significant ($p \leq 0.05$). The equations for all production stages improved in terms of predictability when they were associated with the overall system model. The yearling validation results increased the r^2 value from 0.65 to 0.80.

Table 22. Validation animal gain(x)(kg) when coupled with the plant component.

	N	Equation	r^2	F	$F_{0.05}$
Yearling	77	$y = 0.746x + 56.5$	0.80	298.83	3.76
Calf	38	$y = 0.338x + 298$	0.61	57.2	4.02
Lactating cow	38	$y = 0.658x + 225$	0.57	48.53	4.1

The calf and lactating cow production stages showed only a slight increase in validation results with r^2 values of 0.61 and 0.57, respectively. All equations tended to indicate that the model was over-predicting the animal weight gain in kg with slope estimations ranging from 0.338x to 0.746x (where x = gain in kg). The overall average percent accountability of the model for the animal validation data as part of the whole system was 65.7%, which is fairly close to the level of success achieved by the validated NRC (1996) model (67%).

The slight increase in prediction accuracy for the overall model may be due to the fact that the data used for validation was closest to the intended management scenario specified in the model construction. Also, the calibration of the plant model may have helped to increase the accuracy of prediction.

4.2.7 Summary

In summary, the plant and animal component model validation results appeared to be consistent with the evaluation reports of Gustavsson et al. (1995) and NRC (1996) models. The validation results are also consistent with other models which have been evaluated in terms of model explained variation of ME production in plant and animal weight gain. The animal component used in this pasture- based production system showed less accuracy in predicting than models which predict animal weight gain in controlled environments. The plant component performed well when the grass species were isolated and when pasture types were defined, with the best results associated with the timothy and grasses with similar growth patterns and improved pasture types .

4.3 Management Simulations

Beef system models are used in the prediction of animal performance under different management strategies (Oltjen et al. 1986b). Once a model has been evaluated and the context in which it is applicable has been determined, it can then be used to predict the effects of changing system variables. For example, in beef production, issues such as calving time, feed availability and composition, and housing options would all be variables that effect the profitability of the operation. By varying any one of these factors within the model, a producer may be able to evaluate which specific variable or combination of variables would be the most economical. However, it is essential to take into consideration the accuracy and limits of the model being used when making these decisions.

4.3.1 Management Systems

As with any successful business, one of the objectives in beef production is to be able to operate profitably. Calving time and pasture type are the two management issues that may have an effect on the profitability of the operation. In this study, the effects of two calving seasons (winter and spring) and two pasture types (naturalized and improved) on profit and productivity were simulated.

Both calving systems were simulated with each pasture type (Table 23). The calf output was considered as the only source of income for this study. Production results from the other three animal production stages showed similar trends in weight gain (Appendix F). The animal output (kg) of each simulated system was multiplied by the price of $1.87/kg liveweight to obtain an income estimate on a per calf basis (Nicholson, 1998; Cummings, 1993). The cost of seeding and maintaining an improved pasture was approximated at $60.00/pasture/ season (Thomas and Goit, 1991) and the cost of the naturalized pasture was assumed to be zero. The cost of over wintering the cattle was assumed to be $130.00/head for spring-calving animals and assumed to be $200.00/head for winter-calving animals (Charmley, 1998), although these values are highly variable due to the many external factors which affect them. The sum of the wintering cost and the seeding cost for pasture was determined and then subtracted from the income.

Table 23. Four management systems tested for partial economic performance.

System Number	Calving Season	Pasture Type
1	Spring	Improved
2	Spring	Naturalized
3	Winter	Improved
4	Winter	Naturalized

The results of this simulation indicated that there was a greater weight gain in the fall (Figure 15) and 365 days after birth (Figure 16) for the calves born in the winter. The improved pastures produced an increased weight gain for both calving seasons. The calves born in the winter appeared to be approximately 100 kg heavier than the weight of the calves born in the spring at the end of 365 days for both pasture types (Table 24).

In general, the winter born calves (Table 25) were much heavier than the spring born calves at weaning. Winter born animals on improved pastures seemed to gain more weight than when on naturalized pastures. However, there appeared to be little difference between the weight of the spring born calf on improved and naturalized pastures after 365 days.

Table 24. Calf weight gain(kg) of the four management systems 365 days after birth.

System Number	Calving Season/Pasture type	Calf Gain (kg)
1	Spring/Improved	220
2	Spring/Naturalized	165
3	Winter/Improved	350
4	Winter/Naturalized	267

Table 25. Calf weight gain(kg) of the four management systems in the end of year 1.

System Number	Calving Season/Pasture type	Calf Gain (kg)
1	Spring/Improved	185
2	Spring/Naturalized	140
3	Winter/Improved	350
4	Winter/Naturalized	267

Table 26. Partial economic analysis of the four management systems for animals sold 365 day after birth (per calf basis).

System number	Weight (kg/animal)	Income ($) (kg*$1.87)	Improved pasture cost ($)	Wintering cost ($)	Revenue ($) (income-cost)
1	220	411.4	60	130	221.4
2	165	308.55	-	130	178.55
3	350	654.5	60	200	394.5
4	267	499.29		200	299.29

The economic analysis (Table 26) was based on articles by Nicholson (1996) and Charmley, (1998). The heavier animals (winter born calves) returned the most profit regardless of pasture type. Improved pastured animals produced the highest income ($394.50). The weight of the winter born animal on naturalized pasture was a little less than 100 kg smaller than the calf on improved pasture , and the revenue was $299.29. The spring born animal's return was only slightly more than the cost of over wintering and seeding ($221.40 and $178.55) with approximately 50 kg weight difference.

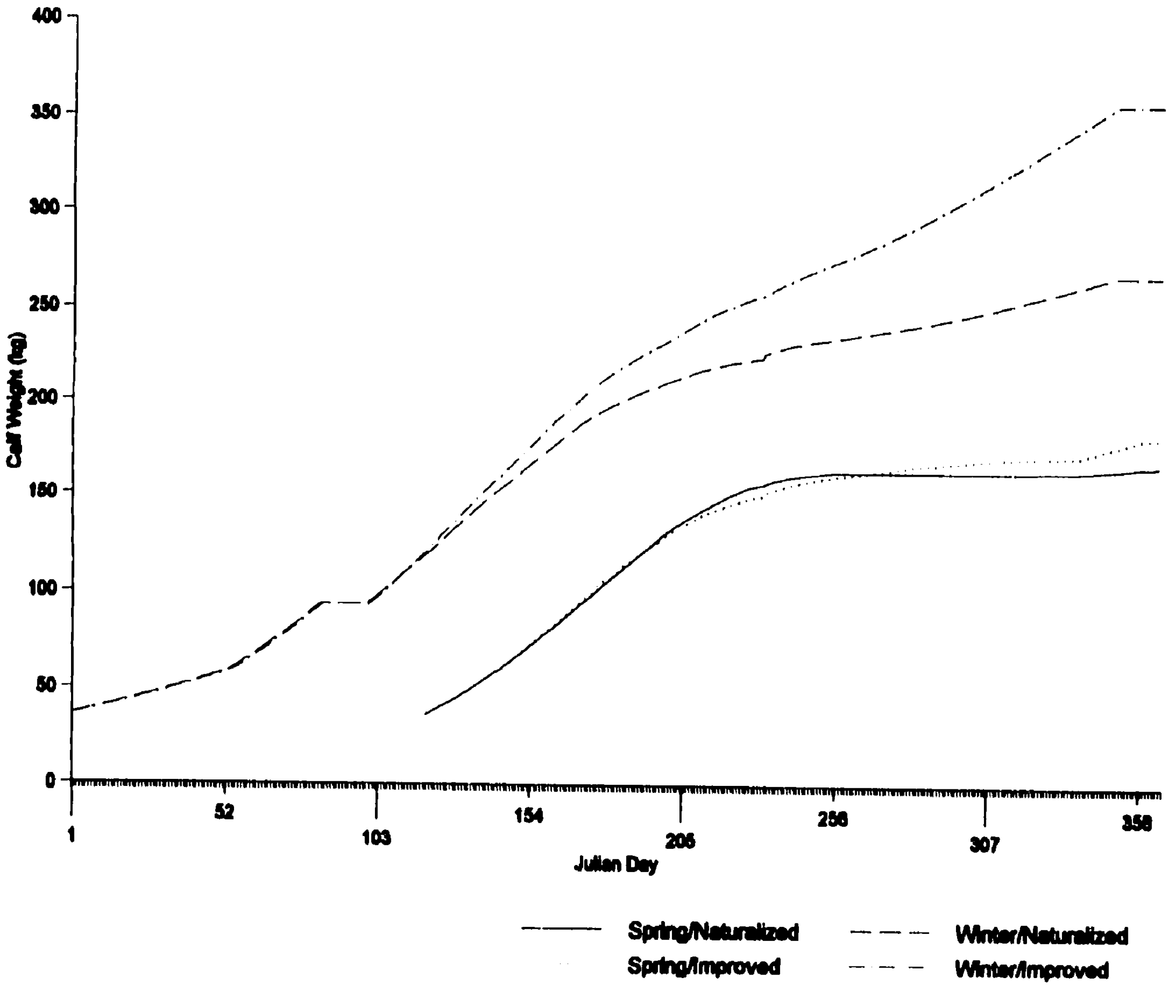

Figure 15. Cumulative calf weight gain (kg) from birth to the end of year 1 simulated using APBM.

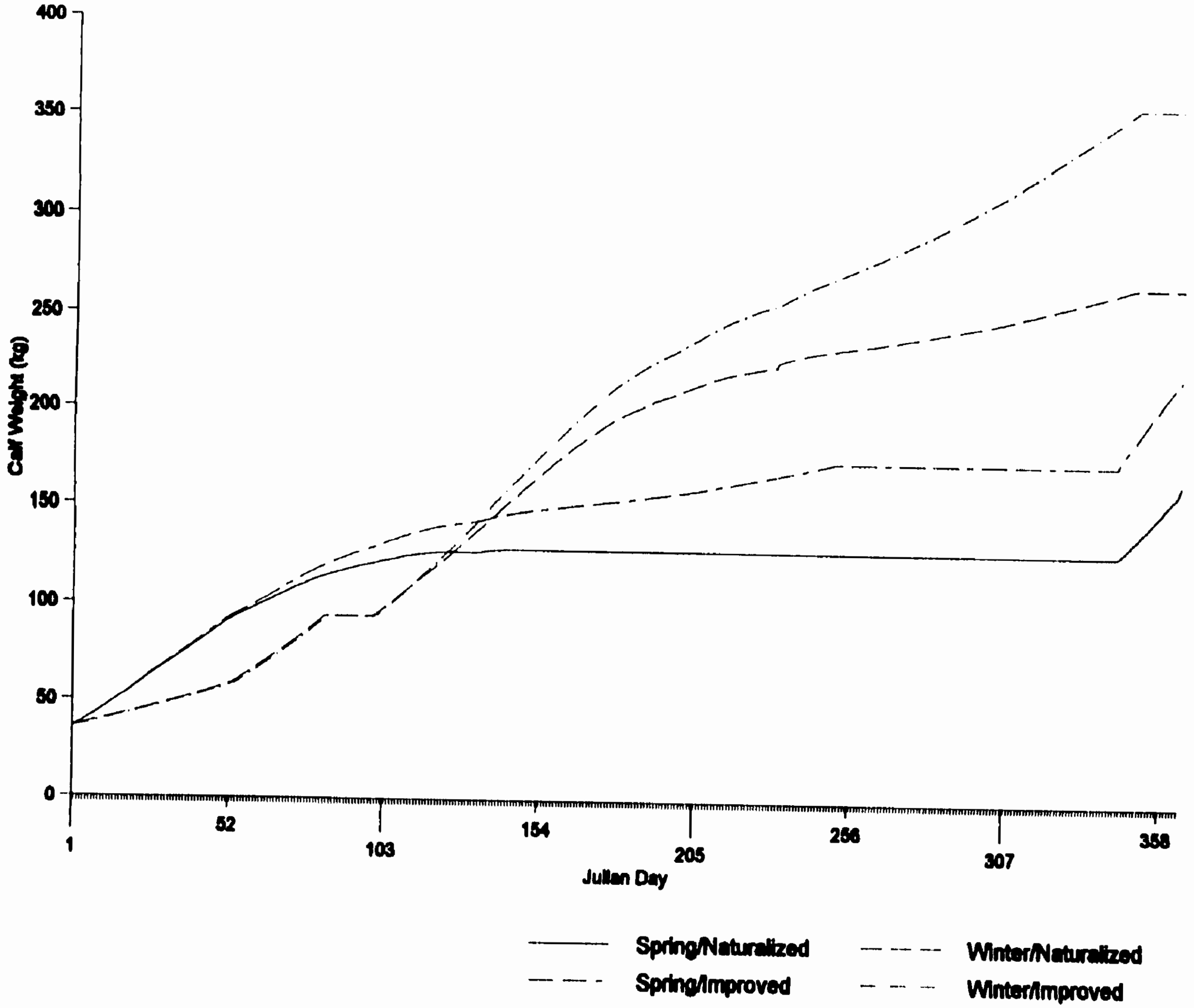

Figure 16. Cumulative calf weight gain (kg) 365 days after birth simulated by APBM.

4.3.2 Model Performance with Specified Management Scenarios

These results suggested that the calves born in winter would return more revenue, even considering the costs of seed and of feeding a lactating animal through the winter. It appeared, from these results, that the age of the calf influences its ability to utilize pasture. This, along with pasture type, contributes to the overall weight gain of the calf. Perhaps, because the winter born calves are closer to weaning weight when they are turned out to pasture, their utilization of pasture feed energy may be higher. The spring born calves, who were receiving nourishment from their dam longer, showed an increase in weight only in the second pasture season.

Laflamme (1988) examined effects of three different calving seasons: fall, winter, and summer. The results showed that a lighter calf was weaned (actual weaning weights) from the summer calving (179 kg) than that of winter calving (220 kg). In that study the animals were all Hereford-Charolais cross raised on improved pasture.

Calf weight from the winter calving APBM system (220 kg) was extremely close to the results obtained in a study by Laflamme(1988). In that study winter born calves at 200 days of age (adjusted weaning weight) weighed 228kg. The spring born calves in the simulated system after 200 days weighed approximately 160 kg, which was about 40 kg less than that of the weaning weight of spring born calves observed by Laflamme (1988).

A research trial by Cooper and Bosveld (1989) performed on a Hereford cow-calf operation, showed weaning weights over three years as 215.9, 227.7, and 238.63 kg, respectively. The animals were reared on a native pasture and the calving time was not specified. Calving time was probably during the winter as the study results are comparable to the winter calving results in the APBM system (weaning weight ≈220 kg). The farm studied by Cooper and Bosveld (1989) was used to help develop the simulated system definition although none of the data was utilized for construction, calibration, or validation.

4.4 Overall Model Performance Summary

The APBM performance was evaluated by comparing predicted results to observed behaviour of the real-life system. Through validation procedures and management scenario simulations, the APBM appeared to represent pasture-based beef production in Atlantic Canada with a reasonable degree of accuracy.

The validation results suggest that the plant component performed better for improved pastures than for naturalized pasture. It predicted successfully for grasses with similar growth patterns to timothy. However, grasses with different growth patterns (low growing grasses and legumes) were not represented well. When compared with weather based models this component demonstrated the same level of accuracy. Statistically, however, the model showed no significant improvement over an empirical representation of pasture ME over time.

The individual animal component validation results showed a moderate representation of animal weight gain over time. The model performed poorly when compared to models developed for tightly controlled management situations. However, when compared to other models developed for pasture management situations (where there is little control over the variables) it demonstrated a similar degree of accuracy.

The APBM validation results showed an increase in the system's prediction of animal weight gain when all components were combined. Approximately 60% of the variation in the animal data was explained by the model. The model was over-predicting calf weight gain (slope estimation of 0.338x), and appeared to have a moderate amount of observed data variation accounted for (r^2=0.61). As the model was preforming within a reasonable range of reality, based on the trials described above, it fulfilled the accuracy expectations.

Chapter 5:

Conclusions and Future Research

5.1 Introduction

When the APBM was compared to other similar modelling applications (Oljten et al. 1986b; NRC, 1996), it successfully predicted the flow of metabolizable energy through a typical pasture-beef production system in Atlantic Canada. However, when the simulated results were compared to actual data (validation) collected from farms and experiments, it became obvious that there were several areas in this model that required model improvement. Due to the fact that the APBM was constructed in a component format, it was possible to evaluate the performance of each individual component before evaluating the overall model. This helped to pin point specific areas where future research is needed and consequently it helped to enhance model precision and its predictive power.

5.2 Plant component

The plant component of the model (Gustavsson et al. 1995) was evaluated with data collected from research trials throughout Atlantic Canada. The performance of this component model was evaluated in four stages: 1) complete data set - no classification by pasture type, plant species, or model calibration; 2) data set divided into two subsets according to species of plant associated with pasture type (improved or naturalized) with no model calibration; 3) data set divided into two subsets according to species of plant associated with pasture type (improved or naturalized) with calibrated model, and; 4) data set divided into thirteen subsets according to individual species (birdsfoot trefoil, bluegrass, bentgrass, creeping red fescue, foxtail, late timothy, meadow bromegrass, orchardgrass, smooth bromegrass, tall fescue, timothy (unknown varieties), white clover, and weeds (anything not included previously)) with the appropriately calibrated models.

The results from the validation stages highlighted six main conclusions :

1) Calibration of the model for pasture type (improved and naturalized) showed an increase in the model's ability to account for ME variation in the validation data.

2) The model appeared to account for most of the variation in ME validation data for species of grasses that are generally classified as improved, and more specifically for grasses with similar growth patterns to timothy .

3) Only a moderate amount of ME variation in the validation data for naturalized grasses was explained by the model.

4) The model did not account for the variation in ME validation data of the two legumes tested in this research (birdsfoot trefoil and white clover).

5) Based on the sensitivity analysis performed for the APBM, the plant component model was most sensitive to changes in critical photoperiod.

6) When the results from the mechanistic plant component model were tested against the validation results from an empirically generated curve statistically, there was no difference between the two sets of validation results. Based on this research, his indicated that the dynamic model by Gustavvson et al. (1995) does not have a superior ability to predict pasture ME when compared to an empirical representation of ME production by a pasture over time.

If the model presented by Gustavvson et al. (1995) is to be used effectively for further modelling research, there are several areas where improvement is required. The three main areas include: 1)differences in grass species' growth, 2) legume growth and production, and 3) interaction of multiple plant species in a pasture.

Detailed information on crop growth differentiation of grass species other than timothy may increase the performance of the plant model. The model appears to simulate ME production well in tall growing and jointed grasses, but it performs poorly when considering low growing, unjointed grasses. Some of the most important low growing grasses in the Atlantic region are bluegrass, creeping red fescues, and bentgrass. Therefore, more sampling of pastures combined with the botanical separation and quality testing of these grasses will help to develop more accurate predictions of ME production. Also, simultaneous weather and management record keeping may contribute to model improvement.

Legumes, such as white clover and birdsfoot trefoil, are common in Atlantic Canadian pastures (Butler et al. 1993), and therefore their growth patterns should be investigated. Preliminary data and cultivar evaluation data that have been collected in this region for birdsfoot trefoil, could be used for model improvement and to aid in the development of predictive equations.

Research on white clover is available for model development. A two year study on growth requirements for white clover by Rodd et al. (1994) has been completed for pure and mixed stands of white clover. Grazing and clipping trials for white clover were reported by Butler et al. (1993). This local data in combination with other information such as Davies,(1996), could provide the knowledge base for developing a quality prediction of the growth characteristics of white clover.

Pastures, recently seeded or naturalized, are rarely pure stands of one species of plant. Therefore, it is important to consider the mixed sward growth dynamics and plant-to-plant interaction in a pasture. The Gustavvson et al. (1995) model used for this system does not take into account any possible species competition that might occur in a pasture. Reports on pasture mix growth and quality (Papadopoulos et al. 1994) may be useful in improving the model's ability to accurately predict pasture ME.

In summary, the Gustavvson et al. (1995) model does a modest job of predicting ME in grasses. As the model was calibrated for specific pasture types and grass species, its ability to predict was enhanced. The model is currently unable to accurately predict ME production for low growing grasses and legumes, and can not yet assess the effect of plant-to-plant interaction.

5.3 Animal Component

The NRC (1996) model was used to represent the animal component of the APBM. This component was evaluated with on-farm data and data obtained from research trials. Two main conclusions were made from the individual animal component validation and sensitivity analysis :

1) The model accounted for a moderate amount of the variation in validation data and consistently showed a slight over-prediction in weight gain.

2) The animal component used in this research was most sensitive to the mud variable and the set value for the estimated mature weight for the breed (standard reference weight).

The animal component of the APBM performed within the range of success that other similar pasture models have achieved. Model improvement concerning animal behaviour, production, and intake on pasture is required. This could help to improve the model's predictive ability. Data gathered on animal intake and movements in combination with plant quality data and how this relates to animal production are areas that require more specific research.

5.4 Overall Model

The overall model combined the plant and animal components to examine the flow of ME through a pasture-based beef production system. The data used to evaluate the system was obtained from a farm in Nova Scotia that included animal production and pasture quality data. This data set represents the typical farm situation for which APBM was designed.

When the animal component model was evaluated as part of the overall system it predicted more accurately than it during the individual evaluation of animal component; 65.7 % versus 57.0%,respectively, of the variation in the animal weight gain on pasture was explained. When the model was used to simulate various typical management strategies it showed that it could be used to predict general economic merit of these systems.

The overall model validation showed that the plant component accounted for approximately 18.0% of the variation in ME production by pasture. This was similar to the results from the first stage of the individual plant component validation and the results obtained by Gustavvson et al. (1995).

To improve the overall system performance perhaps more consideration needs to be placed on the plant-animal interaction. This system did not take into account the effects of animal grazing on pasture plants. This could be the key to improving the overall model prediction.

5.5 Summary

The optimization of pasture use in Atlantic Canada could could help reduce the input costs of beef production and provide a reasonable income for the farmer. However, finding the ideal management practice is not always easy. The use of a system simulation model, such as the APBM, could facilitate the decision making process without having to expend or lose resources unnecessarily.

This research has provided a foundation systems model for the flow of ME through pasture-based beef production system in Atlantic Canada. It has been validated with a degree of success in the animal component, plant component, and overall system. The animal component results suggest that it was achieving the same level of success as other models with similar objectives. It appears that the plant component performance increased as the management and plant species data became more specific.

Overall, the model performed well. When used to examine the results of different management scenarios, the overall model appeared to mimic reality. The results of animal weight gain for each scenario were comparable to actual animal weight gain under real life conditions.

However, the APBM is lacking in several areas. The weak points of this model appear to be similar to the weak points in other models which attempt to predict animal weight gain from pasture. Model improvement in several areas, namely grass species differentiation and environmental effects on animal production, the APBM could be used in evaluating various pasture- based beef production management systems.

APPENDICES

Appendix A

Stella 5.1 (High Performance Systems, 1998), is graphically based and contains entities that represent stocks, flows, converters, connectors, and graphical functions (Figure 17). Stocks, in general, represent state variables or pools of materials. For example, the animal weight is represented by a stock because it is a storage area for the incoming weight gain. Flows represent the material entering and exiting in the stocks. Following the same example, average daily gain or loss would be the flow in and out (respectively) of the animal weight stock. Converters preform any necessary calculations within the model. For example, the convertor could be used to calculate a weight conversion from grams to kilograms. Connectors illustrate the relationships between two other entities. The connection from a convertor to flow would indicate that the convertor is influencing the flow in some way. Finally, a graphical function allows a relationship between an input variable and an output variable to be defined as a graph.

Functions built in to Stella 5.1(HPS, 1998), referred to as "Built-ins", were used to represent the theoretical model in the software. Functions INIT, EXP, IF, ELSE, THEN, AND ,OR, NORMAL, MONTECARLO, ABS, " ^ " and " _" were all used in model construction. The INIT function indicates to the software to utilize the initial value of the specified variable (syntax: INIT(variable)) in the calculation. EXP is the function used to calculate the e^x expression or the inverse of the natural log (Munem and Foulis, 1984). The functions IF, THEN, ELSE, OR, and AND are all used to specify conditions and alternatives for satisfied and unsatisfied situations. The NORMAL function uses a specific set of standard deviations and means to output a succession of normally distributed

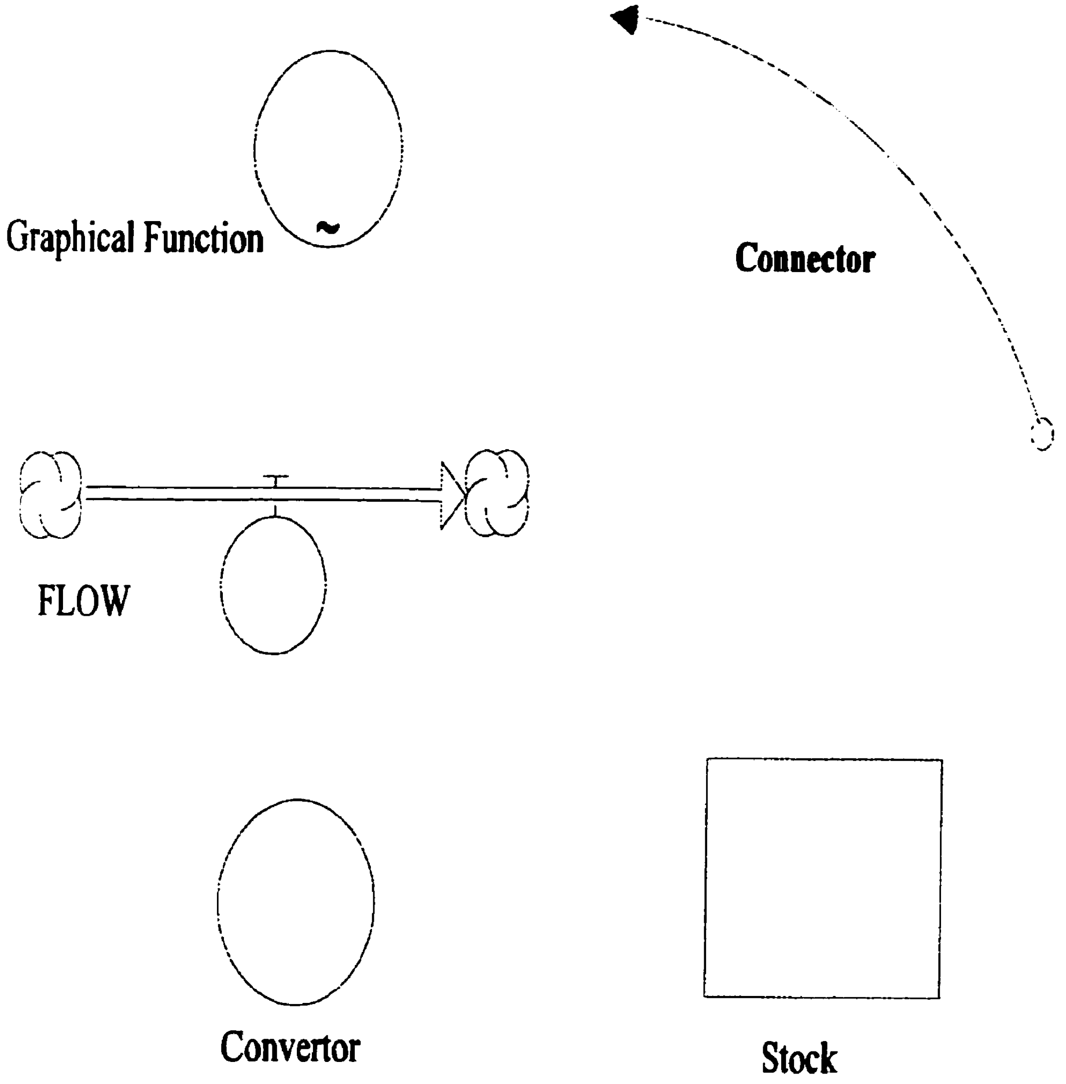

Figure 17. Stella entities.

numbers. The MONTECARLO built-in generates zeroes and ones randomly based on a specified probability. ABS indicates that the value that directly follows in brackets should be an absolute value. The symbol " ^ " is used in Stella 5.1(HPS, 1998) to indicate when a number is be used as an exponent. For example, 4^ 2 would be the same as 4^2. Finally, the symbol " _ " indicates that there is a space between the words.

Stella Research 5.1 (HPS, 1998) has three options for integration: 1) Euler's

Methods; 2) Runge- Kutta 2, and; 3) Runge-Kutta 4. When solving systems of equations over time, the time interval (dt) is an important consideration. This simulation was based on daily time step, therefore Runge -Kutta 2 was chosen as the integration method. This method allowed for a larger time step than Euler's method while still maintaining a reasonable execution time for calculations with minimal errors.

Appendix B

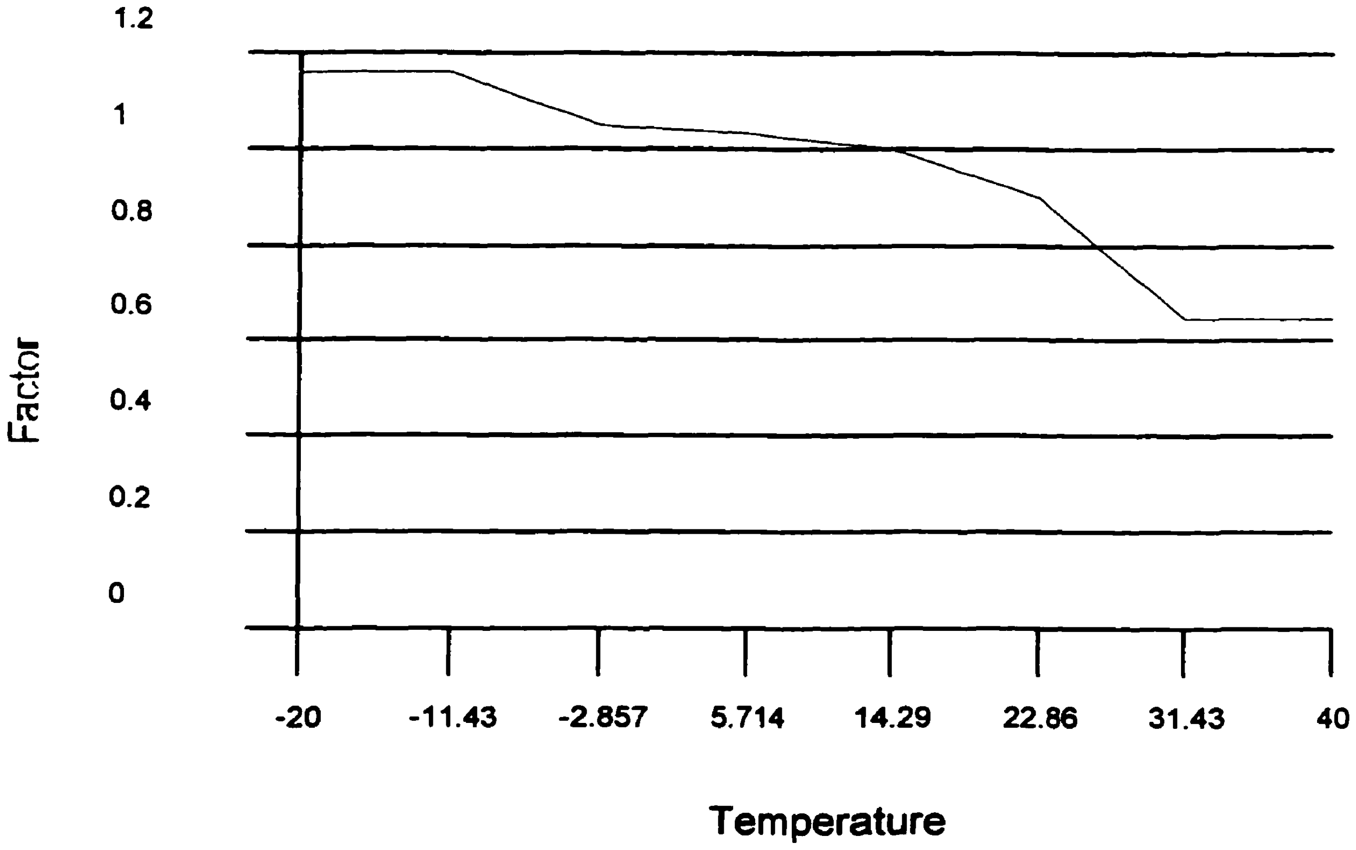

Figure 18. Graphical representaiton of the temperature effect on the energy requirements of cattle.

Appendix C

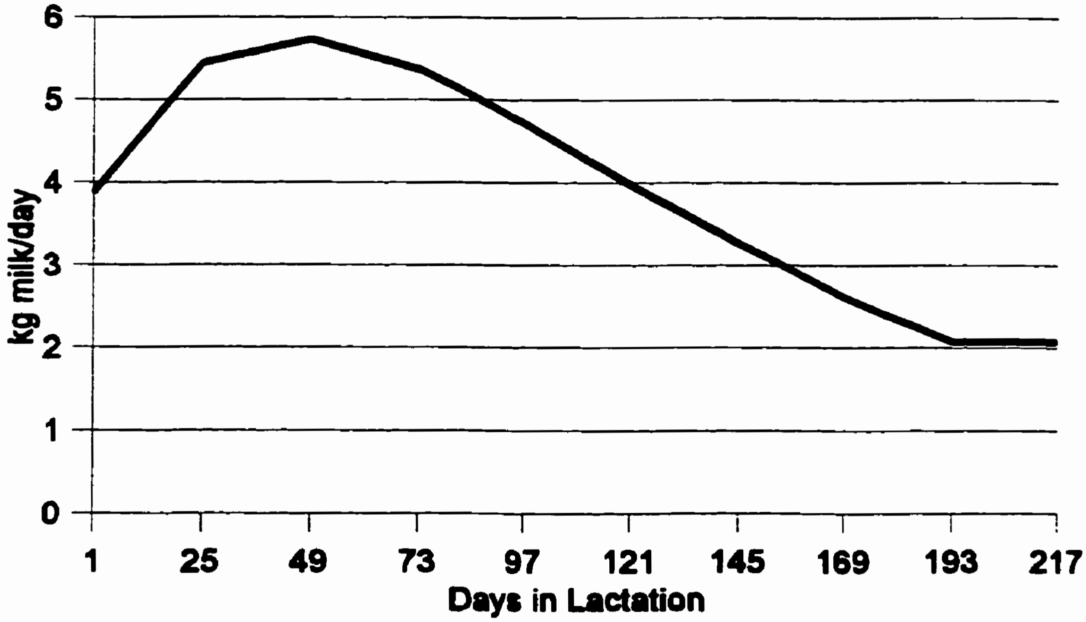

Figure 19. Graphical representation of milk production effect on energy requirements of cattle(NRC, 1996).

Appendix D

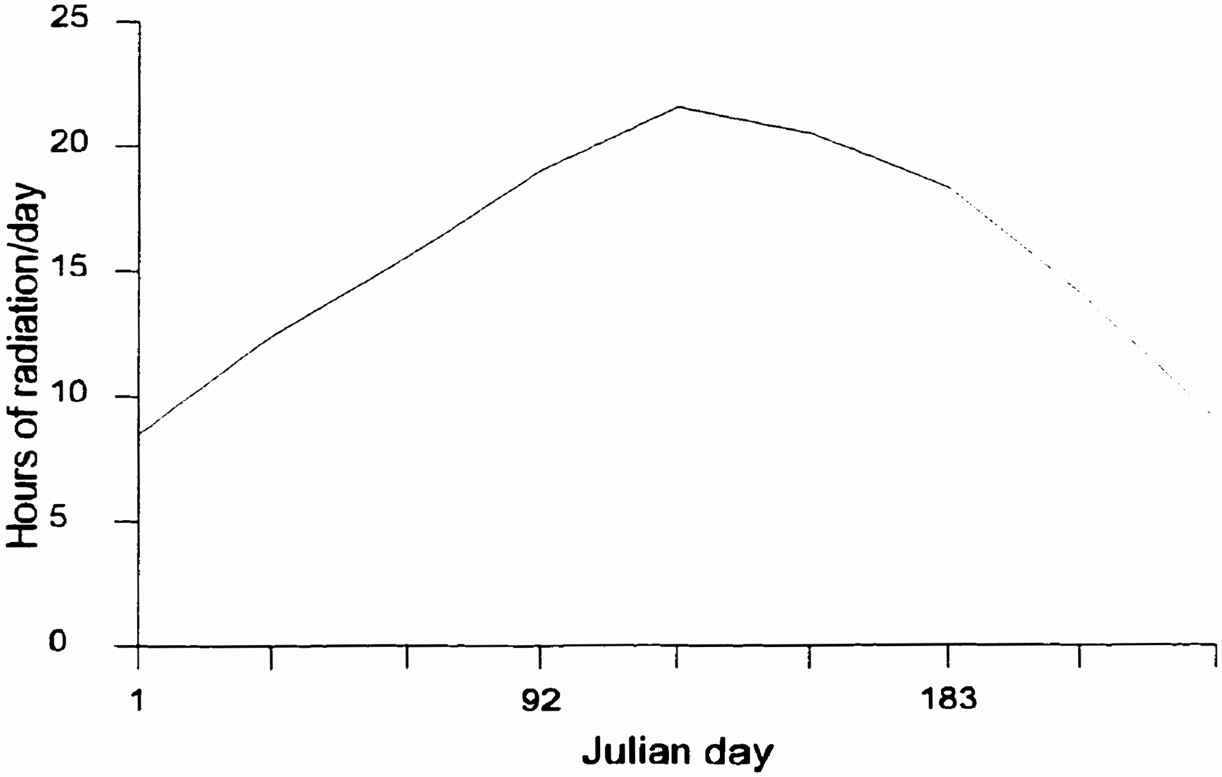

Figure 20. Hours/day of solar radiation based on the CCN for Truro, NS.

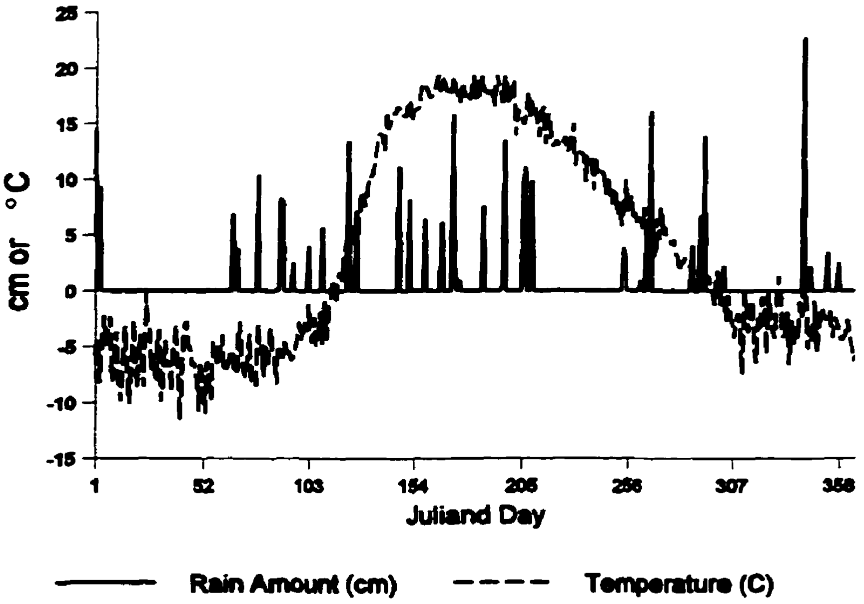

Figure 21. Simulated temperature (° C) and rainfall amounts (cm) for Truro, NS based on the CCN.

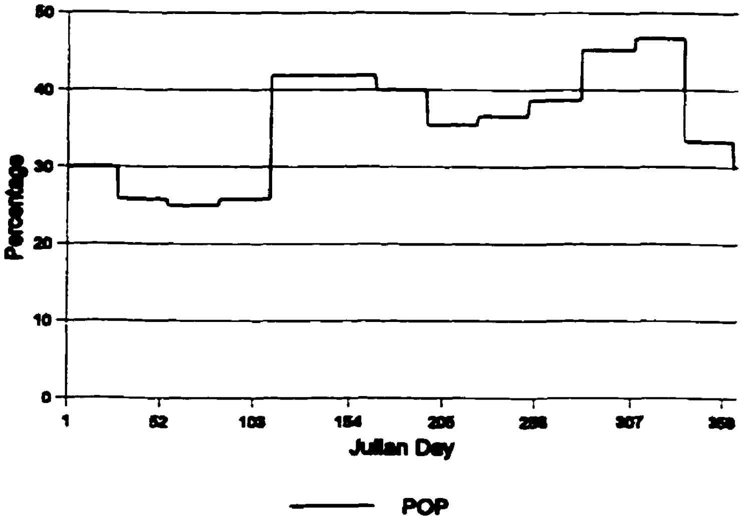

Figure 22. The probability that precipitation will occur in Truro, NS based on CCN.

Appendix E

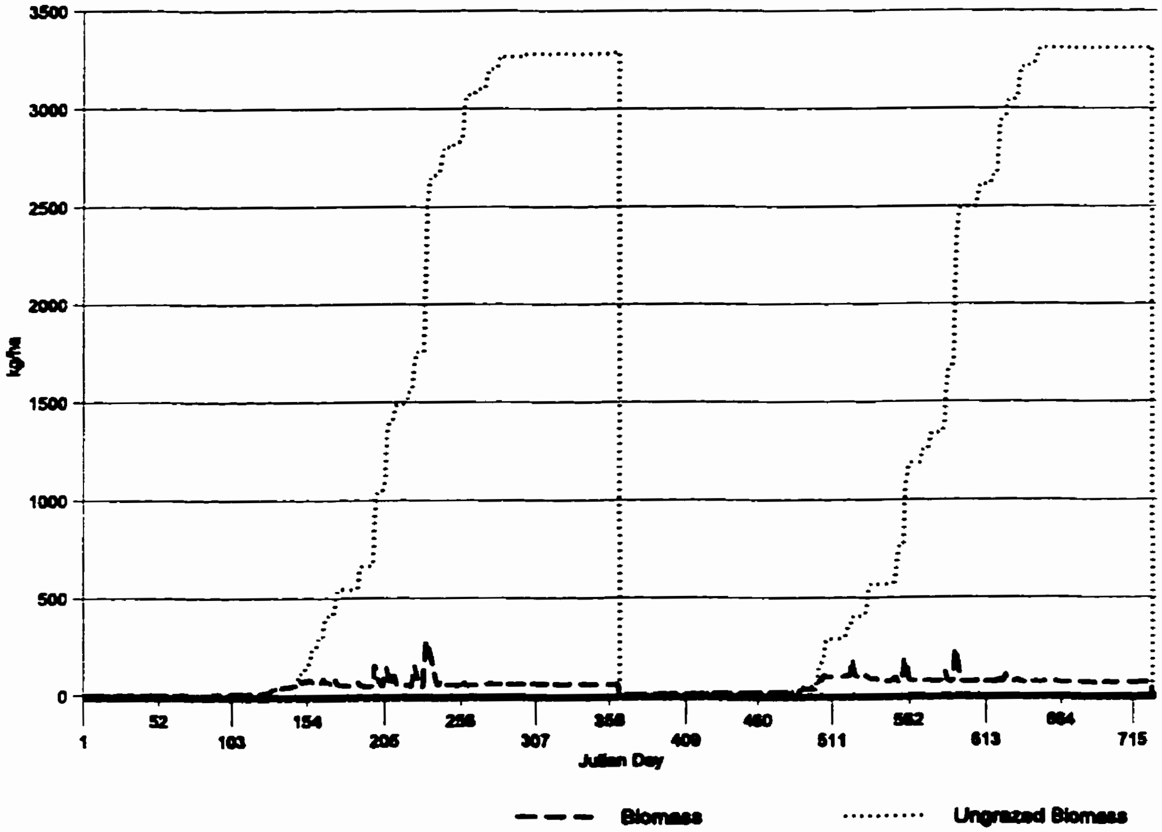

Figure 23. Model output of grazed biomass and ungrazed biomass.

Appendix F

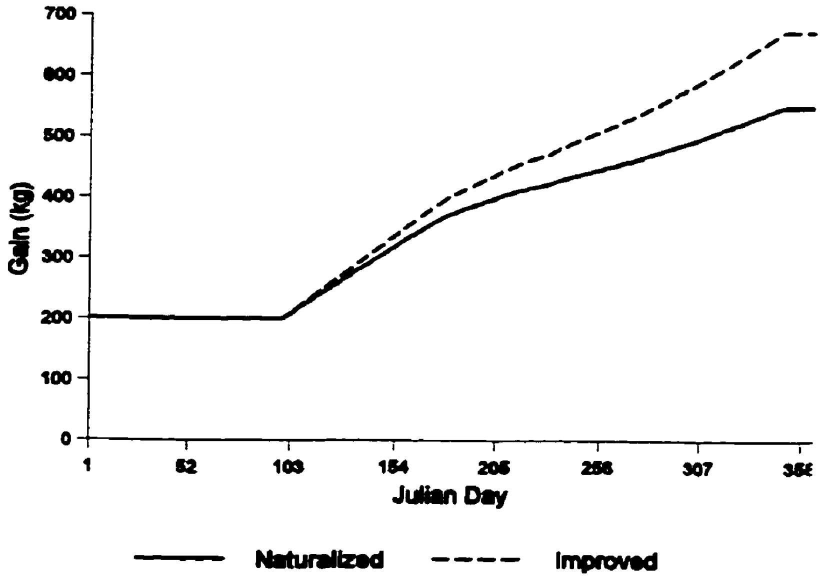

Figure 24.Weight(kg)/day by the yearling on two types of pastures: Naturalized and Improved.

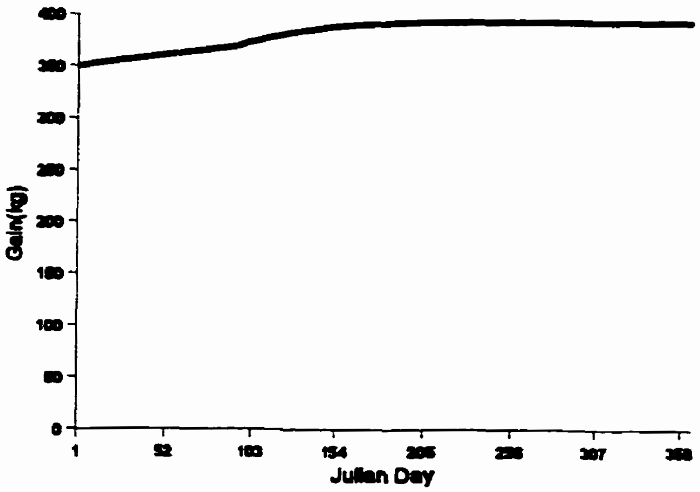

Figure 25. Weight gain(kg)/day of pregnant animal on pasture.

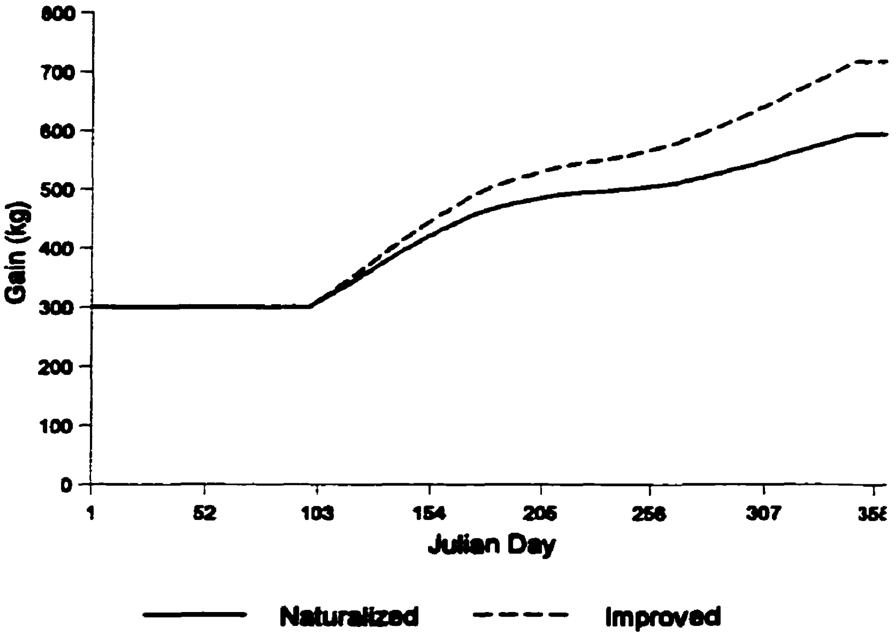

Figure 26. Weight gain(kg)/day of the lactating cow on two types of pastures naturalized and Improved.

Appendix G

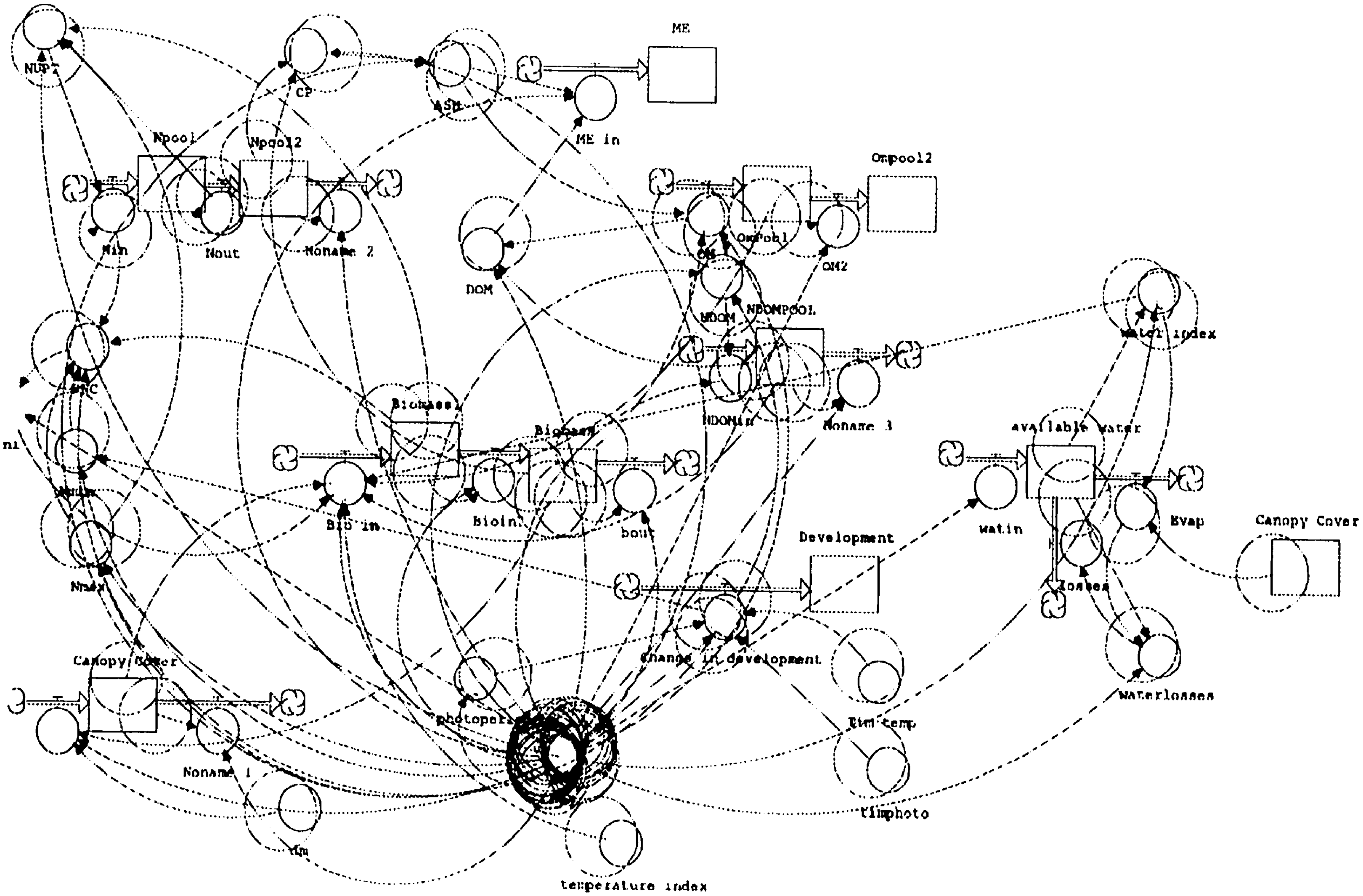

Figure 27. Plant component how it appears in Stella 5.1 (HPS, 1998) including the day connectors.

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