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Full Length Research Paper

Modeling growth of dairy cattle heifers fed elephant grass under stall-feeding system in Uganda

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A simulation model was developed to predict growth rate and days required to reach target mating weight of dairy cattle heifers in a stall-feeding system. Input parameters for the model are gross energy (GE), ash, crude protein (CP), organic matter digestibility (OMD), dry matter (DM), protein degradation variables and heifer initial body weight. Based on these inputs, the model calculates metabolisable energy (ME) and metabolisable protein (MP) that re used to simulate weight gain. Results indicate that growth rate of heifers fed elephant grass as sole feed can be predicted by forage characteristics. Since decisions about heifer management influence future profitability in smallholder dairying, the results of this study are valuable in that being able to predict the growth of heifers can be crucial in providing insight for appropriate intervention.

Key words: Models, weight gain, heifers, elephant grass, simulation.

INTRODUCTION

Stall-feeding of dairy cattle was introduced and promoted in Uganda by non-governmental organizations (NGO) and the Uganda government in order to improve household nutrition, incomes and food security among resource-poor households. Stall-feeding has become an important source of milk and has created employment for many resource poor households in Uganda (Kabirizi, 2006), partly due to Uganda's plan for modernization of agriculture (PMA) policy whose objective is to eradicate poverty through agricultural transformation (UBOS, 2005). Stall-feeding, usually 1 or 2 heads of cattle, has the highest economic returns compared to other cattle management systems (MAAIF, 1996). However, reproductive performance reduce the profitability of smallholder dairy farmers (Nakiganda et al., 2006). For example, heifers in stall-fed dairy cattle are mated at 1.5 - 2.5 years when they have attained about 280 - 300 kg body weight, and the average age at first calving is $\geq$ 2.5 years (Twinamatsiko, 2001) as compared to 2 years at first calving in the developed world (Dobos, et al., 2001; Evans et al., 2006). This difference is partly due to feeding. Stall-feeding is based on elephant grass (*Pennisetum purpureum*) as major forage (Muwanga, 1994; Tumutegyereize et al., 1999), because of its high biomass yield compared to other grasses (Boonman, 1993; Anindo and Potter, 1994). However, little information is currently available on dairy heifer performance from elephant grass as a sole feed in stall-feeding dairy system. And yet decisions about heifer management influence future profitability (Mourits et al., 1997). Since the interaction between feed resources and livestock revolve mostly around the supply of nutrients and energy in feed, there is need to use models capable of predicting animal performance from forage and animal characteristics (Thornton and Herrero, 2001). Moreover studies based on simulation models are useful in the evaluation of various rearing strategies, and the insights gained can be used further to develop dynamic optimisation models (Mourits et al., 1997). The objective of this study was to predict weight gain and time to attain recommended mating weight of dairy heifers based on forage characteristics, using a simulation model in a stall-feeding dairy system with elephant grass as sole feed.

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Table 1. Nutrient composition and digestibility, degradability, energy and age of Napier grass[a].

Age	DM	DOMD	CP	GE	ADIN	*a*	*b*	*c*	Reference
-	192	808	-	-	-	-	-	-	Hassan et al. (1983)
-	234	-	196.9	-	-	-	-	-	Hassan et al. (1979)
10	182.7	-	81.8	15.4	-	-	-	-	Muia et al. (2001a)
15	238.6	-	53.3	16.9	-	213	672	0.04	Muia et al. (2001a)
10	180	-	83	16	-	-	-	-	Muia et al. (2001b)
15	240	-	53	17	-	-	-	-	Muia et al. (2001b)
10	183.1	-	84.1	16.1	-	-	-	-	Muia et al. (2000)
15	237.8	-	53	16.8	-	-	-	-	Muia et al. (2000)
-	176	-	68.4	-	-	-	-	-	Nyambati et al. (2003)
-	-	524	115.4	-	1.3	211	541	0.03	Kabi et al. (2005)
-	155	571	118	-	-	-	-	-	Kariuki et al. (1998)
M[b]	-	560	61	15.6	-	-	-	-	Mlay et al. (2006)
6-8	-	692	102.5	-	-	-	-	-	Mpairwe et al. (1998)

[a] DM = dry matter (g/kg); DOMD = digestible organic matter (g/kgDM); CP = crude protein (g/kgDM); ADIN = acid detergent insoluble nitrogen (g/kgDM); GE = gross energy (MJ/kgDM); *a* = water soluble fraction (g/kgCP); *b* = potentially degradable nitrogen other than water soluble fraction (g/kgCP); *c* = degradation rate per hour of the *b* fraction (g/kgCP).
[b] M refers to mature, no specific age given.

MATERIALS AND METHODS

This section summarises the procedures, assumptions and equations used to develop a growth model of dairy heifers from weaning to mating weight, for forage-based stall-feeding dairying system.

Feed composition

Nutrient composition, digestibility and degradability parameters are shown in Table 1. However, due to lack of comprehensive nutrient composition data on elephant grass from a single experiment, values from several experiments were pooled to form the basis for parameter estimation.

Energy value of feed

The energy value of feed was estimated based on AFRC (1993) as follows:

$$ME(MJ/kgDM) = 0.0157 \times DOMD(g/kgDM) \quad (1)$$

Where ME is metabolisable energy; DOMD is digestible organic matter in a feed, and is estimated as

$$DOMD = OMD \times (1000 - total\,ash)/1000 \quad (2)$$

Where OMD is organic matter digestibility (g/kg)

$$FME = ME \times \left(0.467 + 0.00136 \times ODM - 0.00000115 \times ODM^2\right) \quad (3)$$

Where FME (MJ/kgDM) is fermentable metabolisable energy; ODM is oven dry matter content (g/kg)

Protein value of feed

Estimation of the metabolisable protein (mp) from crude protein (CP) involves the following calculations (AFRC, 1993). Definitions of symbols used are in Table 2.

$$UDP = CP - \{QDP + SDP\} \quad (4)$$

$$SDP = \{(b \times c)/(c + r)\} \times CP \quad (5)$$

$$QDP = a \times CP \quad (6)$$

Where r is calculated as follows

$$r = -0.024 + 0.179\left\{1 - e^{(-0.278L)}\right\} \quad (7)$$

Where L is level of feeding as a multiple of MJ of ME for maintenance.

$$MCP = FME \times y \quad (8)$$

Where y is microbial protein yield in the rumen (gMCP/MJ of FME), and is calculated as:

$$y = 7.0 + 6.0\left\{1 - e^{(-0.35L)}\right\} \quad (9)$$

$$DUP = 0.9\{UDP - 6.25ADIN\} \quad (10)$$

$$DMTP = 0.6375MCP \quad (11)$$

$$MP(g/d) = 0.6375MCP + DUP \quad (12)$$

$$ERDP = 0.8QDP + SDP \quad (13)$$

If ERDP supply is less than (or equal to) ERDP required, then

Table 2. The definition of symbols and terminology.

Symbol	Definition	Units
a	Proportion of water soluble Nitrogen in the total Nitrogen of a feed	Unit-less
ADIN	Acid detergent insoluble nitrogen in a feed	g/kgDM
b	Proportion of potentially degradable N other than water soluble N of a feed	Unit-less
c	Fractional rumen degradation rate per hour of the *b* fraction of feed N	Unit-less
CP	Crude protein in of a diet or in a feed	g/kgDM, g/d
DMTP	Digestible microbial true protein (= metabolizable protein from microbes)	g/d, g/kgDM
DUP	Digestible undegraded protein (N x 6.25)	g/kgDM, g/d
FME	Fermentable metabolizable energy of a diet	MJ/d, MJ/kgDM
MCP	Microbial crude protein supply	g/d, g/kg
MP	Metabolizable protein	g/d, g/kgDM
MTP	Microbial true protein	g/d, g/kg
QDP	Quickly degradable protein (N x 6.25) of a diet or in a feed	g/d, g/kgDM)
r	Rumen digesta fractional outflow rate per hour	Unit-less
SDP	Slowly degradable protein (N x 6.25) of a diet or in a feed	g/d, g/kgDM
UDP	Undegradable dietary protein (N x 6.25) of a diet or in a feed	g/kgDM

$$MCP(g/d) = ERDP(g/d) \quad (14)$$

Else

$$MCP(g/d) = FME(MJ/d) \times y(gMCP/MJ\,FME) \quad (15)$$

Estimation of intake

According to AFRC (1993) the dry matter intake (DMI) is estimated as follows:

$$DMI(kg/d) = MER/(M/D) \quad (16)$$

Where MER is Metabolisable Energy Requirement (MJ/d), M/D is metabolisable energy (MJ/kgDM). This estimation of DMI is appropriate where daily gain is predetermined. In a case where the DMI depends on forage availability and daily gain is not known forehand, the intake can be estimated based on experimental observations. We used an estimate of 2.7% of body weight based on Kariuki et al. (1998) value of 2.94%, Diaz-Solis et al. (2006) value of 2.54% and Blomquist (2005) value of 2.5 - 3.0% of the body weight. Therefore

$$IF\ \ Fa \geq 0.027*W,\ \ THEN\ \ DMI = 0.027*W,\ \ ELSE\ \ DMI = Fa \quad (17)$$

Where Fa is available forage.

Protein requirements

The metabolisable protein is based on AFRC (1993). Metabolizable Protein requirement for maintenance (kg/d) is estimated as

$$MP_m = 2.30W^{0.75} \quad (18)$$

Metabolizable Protein requirement for growth (kg/d) is estimated as

$$MP_f = C6\{168.07 - 0.16869W + 0.0001633W^2\} \times \{1.12 - 0.1223\Delta W\} \times 1.695\Delta W \quad (19)$$

Where MP_f is metabolizable protein requirement for liveweight gain (kg/d), $C6$ is a correction factor ranging from 0.8 -- 1.0, W is liveweight of the animal (kg).

Energy requirements

The energy requirement is based on AFRC (1993) and is calculated as follows:

$$M_{mp}(MJ/d) = (E_m/k) \times \ln\{B/(B-R-1)\} \quad (20)$$

Where M_{mp} is ME requirement for both maintenance and production, E_m (MJ/d) is the sum of animal's fasting metabolism (F) and activity allowance (A = 0.0071W) for zero-grazed heifers, R is the scaled energy retention. The fasting metabolism, MJ/(kg fasted weight)$^{0.67}$, is defined as:

$$F = 0.53(W/1.08)^{0.67} \quad (21)$$

The factors B and k are calculated from the efficiencies of utilization of ME as follows:

$$B = \frac{k_m}{(k_m - k_f)} \quad (22)$$

$$k = k_m \times \ln\left(k_m / k_f\right) \quad (23)$$

Where k is the efficiency of utilization of ME (Metabolizable Energy) for a given metabolic process, B is a derived parameter to predict energy retention, k_m is the efficiency of utilization of ME for maintenance, k_f is the efficiency of utilization of ME for weight gain. Both k_m and k_f can be calculated as follows:

$$k_m = 0.35q_m + 0.503 \quad (24)$$

$$k_f = 0.78q_m + 0.006 \quad (25)$$

Where q_m is the metabolizability of [GE] at maintenance, [ME]/[GE], where GE is the gross energy of a diet (MJ/d or MJ/kgDM).
Scaled energy retention (R) is calculated from

$$E_f = C4\left(EV_g \times \Delta W\right) \quad (26)$$

Where $C4$ is the correction factor for ME for heifers (= 1.1) and then:

$$R = \frac{E_f}{E_m} \quad (27)$$

Where E_f is Net Energy retained in growing animal (MJ/d), E_m is Net Energy for maintenance (MJ/d).

Predicting live weight gain

Predicting live weight gain involves the following steps:

Step 1. Energy Value of weight gain

This is given by the expression

$$EV_g = \frac{C2\left(4.1 + 0.0332W - 0.000009W^2\right)}{\left(1 - C3 \times 0.1475\Delta W\right)} \quad (28)$$

Where EV_g is energy value of tissue gained (MJ/kg), ΔW is live-weight change (kg/d), $C2$ is a correction factor (range 1.00 - 1.30) for mature body size and sex of animal; $C3$ is a correction factor for plane of nutrition (L), 1 when $L >$ 1 and 0 when $L <$ 1. These correction factors are given in AFRC (1993).

Step 2. Energy retention

Scaled energy retention (R) is as defined in equation 27.

Step 3. Metabolisable Protein requirement for growth

Equation 19 is rearranged to estimate weight gain based on MP.

Step 4. Weight gain

Equation 26 is rearranged to give

$$\Delta W = \frac{E_f}{\left(C4 \times EV_g\right)} \quad (29)$$

By combining the two equations 28 and 29 that contain the term ΔW, we get

$$\Delta W = \frac{E_f}{\left(C4X + 0.1475E_f\right)} \quad (30)$$

Where $X = C2\left(4.1 + 0.0332W - 0.000009W^2\right)$ is taken from equation 28.

DESCRIPTION OF THE SIMULATION MODEL AND THE DATA USED

Description of the simulation model

It is assumed that the animal is not constrained in any other way apart from the supply of crude protein and energy. Holstein Friesian heifers of less than 1 year and weighing less than 150 Kg of bodyweight at the start of the simulation are used in this model. The feed input parameters are DM, OMD, GE, ash, CP, CP degradation variables (*a, b, c*, Table 2 contain definitions), acid detergent insoluble nitrogen (ADIN). Animal characteristics are initial weight and level of feeding. The dry matter intake is set at 2.7% of animal's weight as explained earlier. All other parameters are calculated by the model. If effective rumen degradable protein (ERDP) supply is less than (or equal to) ERDP required, then microbial crude protein (MCP) is equal to ERDP else MCP is equal to fermentable metabolisable energy (FME) multiplied by microbial protein yield (y).

The simulation model is coded in VENSIM 5.5 (The Ventana Simulation Environment, Ventana Systems, Inc.), based on differential equations with a 1-day time step (Δt = 1 day). Figure 1 shows the simulation logic of the model. After part of ME and MP have been used for maintenance, daily gain (DG) is dependent on the balance between Metabolisable Energy for growth (MEg) and Metabolisable Protein for growth (MPg); if potential growth due to metabolisable protein (Gp) is greater than the potential growth due to metabolisable energy (Ge), then MEg is considered limiting and the growth is determined by Ge. Else if potential growth due to metabolisable protein (Gp) is less than potential growth due to metabolisable energy (Ge), then MPg is considered limiting and the growth is determined by Gp. The simulated DG is then added to the weight to get a new weight (W), and the process is repeated for the desired number of days.

Description of the data sets used in calibration and evaluation

The experiments from which these datasets (Table 3) were generated were either on the effect of supplementation on

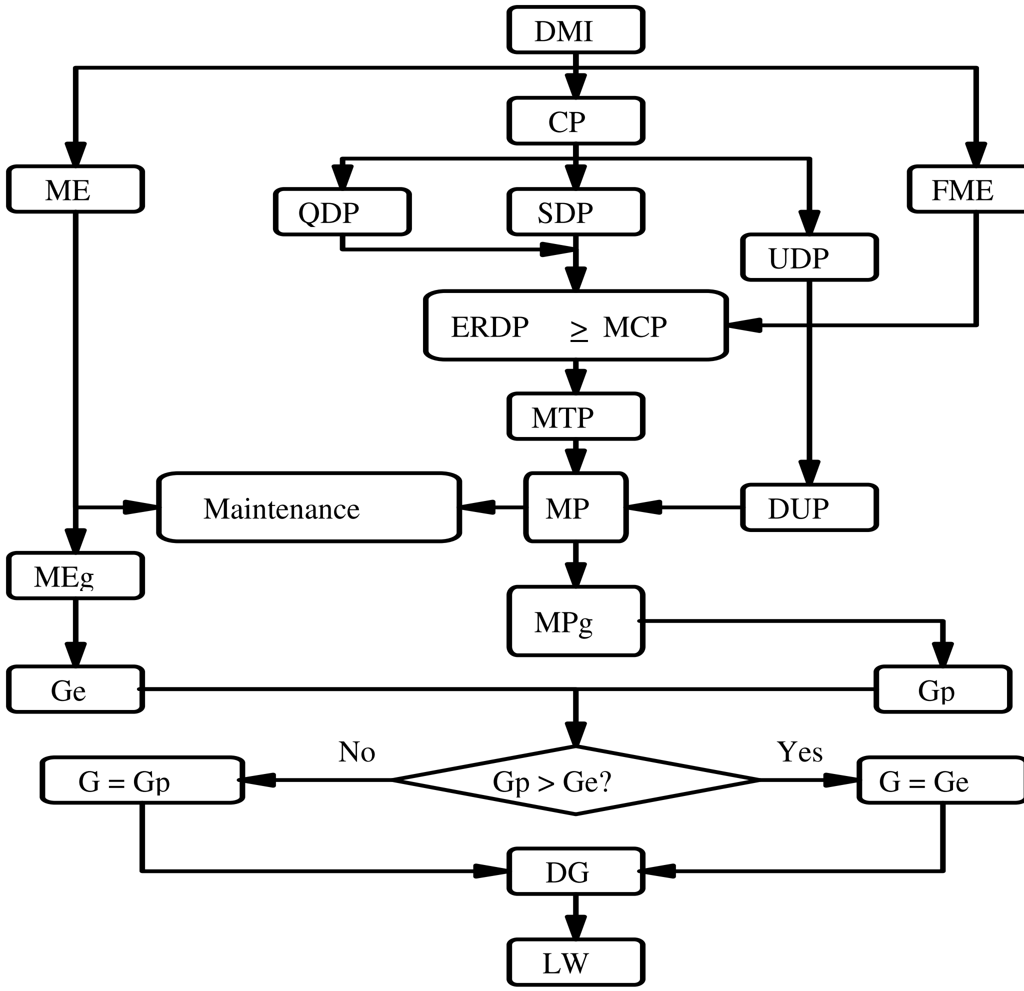

Figure 1. Simulation logic of the weight gain of heifers fed napier grass.

Table 3. Chemical composition of the forage used in model development and evaluation[a].

DM	CP	Ash[b]	*a*	*b*	*c*	ADIN	GE	Age	References
Model development									
-	-	111	0.2468	0.4942	0.02	1.3	-	1 m	Kabi et al. (2005)
176	68.4	-	-	-	-	-	-	1-1.5 m	Nyambati et al. (2003)
183	84	-	-	-	-	-	16.1	10 wks	Muia et al. (2000)
Model evaluation									
-	-	-	0.213	0.672	0.04	-	16	10 wks	Muia et al. (2001a)
155	118	204	-	-	-	-	-	6 wks	Kariuki et al. (1998)
-	115.4	-	0.211	0.541	0.03	-	-	1 m	Kabi et al. (2005)

[a] DM, CP, Ash and ADIN in g/kgDM; *a*, *b* and *c* are proportions; GE in MJ/kgDM; Age in weeks (wks) or metres (m).
[b] Where DOMD is not known, then Ash is used according to Equation 2.

degradability (Kabi et al., 2005; Kariuki et al., 1998; Muia et al., 2001b) or effect of supplementation on weight gain (Kariuki et al., 1999; Kariuki et al., 1998; Muia et al., 2000). Degradability parameters required as inputs for the simulation model were gotten from experiments that fall in the degradation category. For growth experiments, only the controls (where the basal diet was only elephant grass) were used as data sources for the simulation model.

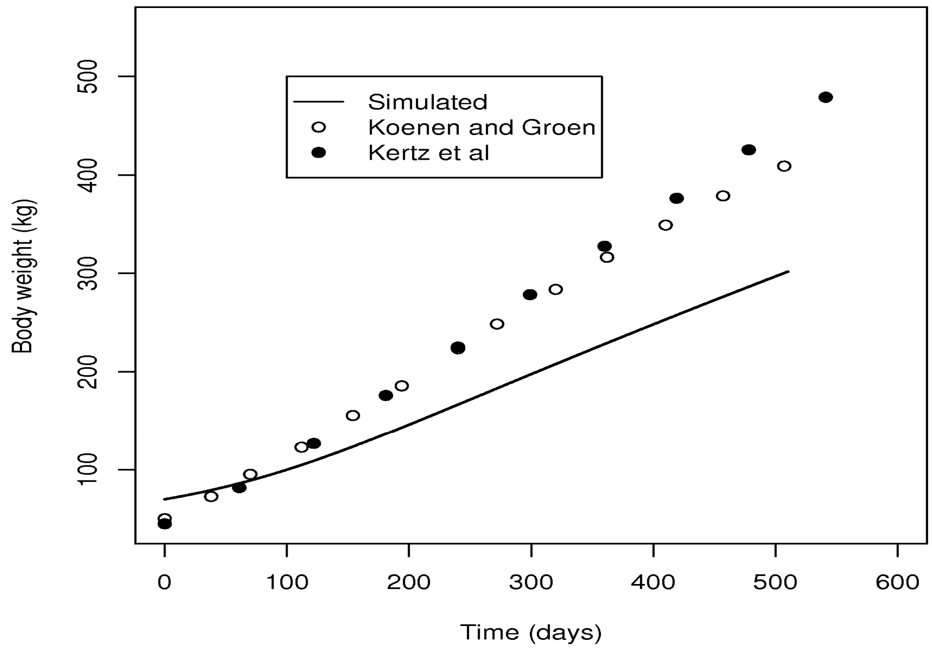

Figure 2. Comparison of model body weight output with observed and fitted values.

ANIMALS

The animals used in this experiment are Holstein Friesian heifers weaned at 3 - 7 months of age as commonly practiced in the smallholder management system in uganda. In this system of management, the calves are exposed to forage in their first week of life. This helps in the stimulation of rumen growth and development so as to sufficiently handle forage when they are weaned.

RESULTS AND DISCUSSION

Model calibration

According to AFRC (1993) the proportion of DUP in UDP varies from nil to 0.9, depending on the feed, its composition and pretreatment. Parameters that describe protein degradation in the rumen (a, b, c), and ADIN which contributes directly to fecal N levels, are highly variable (Webster, 1993) even when determined for the same samples at different laboratories. Therefore, these parameters were selected as the starting point for the calibration. We used the values of Table 3 for calibration. Although the calibration datasets are the same ones used to derive parameters for the model, they provide an indication of the ability of the model to predict daily gain following manipulation of model parameters to improve accuracy (Hill et al., 2006).

Model evaluation

From the data used to develop and evaluate the model it was not possible to compare the model's predicted growth curve with observed curve; this was because only averages were given in the observed data. Nonetheless, to appreciate the structure of the simulated curve, we compared the simulated growth curve to that of Kertz et al. (1998) and the fitted growth curve by Koenen and Groen (1996) as shown in Figure 2.

The difference can be explained by the differences in the feeding. For Koenen and Groen (1996) the data used for fitting the growth model was from heifers fed concentrate, hay, pasture and grass silage for *ad libitum* intake; thus the maximum growth rate of Von Bertalanffy curve equaled 0.8 kg/d and was reached at 212 days of age. For Kertz et al. (1998) grower concentrate, alfalfa hay and grass hay were given to the experimental heifers; this made it possible to attain post-weaning daily body weight gain of 0.82 to 0.93 kg.

Model use

Crude protein in elephant grass can be as low as 53 g/kg DM and as high as 196.9 g/kg/DM (Table 4). Based on these values we used the simulation model to predict corresponding increase in DG (Table 5). The predicted loss in weight of -0.01 kg/day at 50 g/kgDM of CP is due to the supplied CP falling below the maintenance requirements. From Table 5, it is possible to achieve higher growth rates and consequently reduce on the number of days taken to target mating weight of the heifers by feeding forage high in CP. DM digestibility and CP content (Ogwang and Mugerwa, 1976) and rumen

Table 4. Predicted and observed DG, DMI and CPI for heifers weighing 143 kg and fed for 104 days[a].

Forage	DG	W[b]	DMI	CPI	Time	References
Elephant grass	0.50	143.30	5.00	0.59	104	Observed
6 weeks old	0.51	143.30	4.58	0.54	104	Predicted

[a] DMI, CPI, DG in kg/d; W in kg; Time in days; [b] W=initial weight; [c] Kariuki et al. (1998).

Table 5. Predicted daily gain of a 70 kg heifer, and days to target weight of 300 kg as a function of CP of the forage[a].

CP	50.00	75.00	100.00	125.00	150.00	175.00	200.00
DG	-0.01	0.17	0.34	0.50	0.66	0.81	0.94
Days	-	1073	653	458	343	275	229

[a] DG in kg/day; CP in g/kgDM; The forage characteristics used as inputs were based on elephant grass at 6 weeks of age.

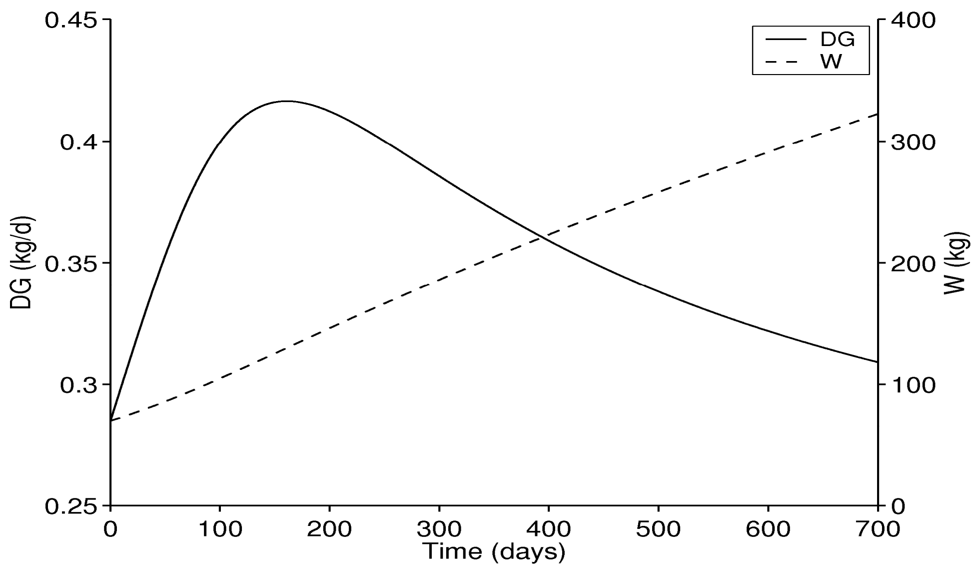

Figure 3. Simulated DG and body weight (W) at CP 80 g/kgDM and ME 7.14 MJ/kgDM.

degradation (Muia et al., 2001b) of elephant grass decline with age. This decline is mainly due to increase in acid detergent fibre (ADF), neutral detergent fibre (NDF), and acid detergent lignin (ADL) and a decrease in CP content (Minson, 1990). It is therefore apparent that feeding elephant grass when CP is high could result in better performance. In Figure 3, DG increases from the start of the simulation to 150 days and starts to decline.

This pattern of high growth rate in the early stages of life, followed by a continuous slow increase as the animal gets older is well established (Vaccaro and Rivero, 1985) and is due to lower maintenance requirements at smaller body weight (Kertz et al.,1998).

According to MLD (1991) recommendations in the smallholder dairy systems, weaning weight for dairy heifers is 70 kg and a target of 300 kg to be attained by 18 months of age for first service. For this target to be met the heifers are assumed to gain at least 0.5 kg per day. This means that heifers fed elephant grass as a sole feed are unlikely to attain the target mating weight in recommended time. However, it is important to note that there was lack of data to test the model from 70 kg to 300 kg; the model was evaluated for heifers of initial weight 143 kg growing to 196 kg. In conclusion, results from this study indicate that growth rate of heifers fed elephant grass as sole feed can be predicted based on forage characteristics. However, the model has limitations in that the data used for development and evaluation of the model was not comprehensive. Nevertheless, the results of this study are valuable in that being able to predict the growth of heifers can be crucial in providing insight for appropriate intervention. Further research on heifer performance in stall-feeding dairy system is needed to accumulate adequate data for developing and evaluating the simulation models of heifer growth where elephant grass is the sole feed.

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