Predicting economic implications of weaning programs in young dairy calves

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Introduction

Considerable research has been reported in the past 15 years regarding effects of feeding and management on growth of calves. Traditional methods of feeding limited milk or calf milk replacer (**CMR**) have generally been replaced by increased quantities of liquids prior to weaning as several studies have indicated that early life nutrition may impact future milk production (Soberon et al., 2012, 2013; Gelsinger et al., 2016). Ages at weaning have also been evaluated (Eckert et al., 2015; Khan et al., 2016) even to 17 weeks of age (Schwarzkopf, et al., 2019). Incorporating new data into recommendations for on-farm management is required, particularly to meet farm-specific goals such as maximal rate of gain vs. lowest cost.

In the past 10 years, the calf research team at Provimi North America (a Division of Cargill, Inc.) has evaluated numerous changes to liquid feeding programs and calf starter formulation to better understand their effects on health and growth to four months of age. Many of these studies were summarized in a meta-analysis by Hu et al. (2020). We also reported several studies that evaluated composition of calf starters and indicated that starch supports greater levels of BW gain compared to NDF (Hill et al., 2010; Chapman et al., 2016; Hill et al., 2016a, b; Dennis et al., 2018a, b; Quigley et al., 2018). We found that starch more rapidly stimulates rumen development and nutrient digestibility and differences in NDF digestion may still exist as late at 16 weeks of age. Further, greater amounts of liquid fed preweaning delays rumen development and slows changes in nutrient digestion. The net effect of high fiber starters and high milk allowances is delayed rumen development. Weaning calves without these considerations often results in calves with poor post-weaning growth ("weaning slump") and predisposition to disease due to stress. Our data suggests that formulation of starter and amount of liquid fed can affect preparation for weaning and should be considered in any calf management recommendations.

Most farmers monitor neither calf BW nor intake on a routine basis. Therefore, it is difficult to evaluate effects of changes in nutrition or management in real time. However, it is possible to use a modeling approach to estimate effects of different programs on preparation for weaning and expected growth in these programs. We have developed a model of growth that allows modification of feeding programs to meet on-farm goals and predict growth, intake, cost, and efficiency to 4 months of age.

Assumptions Used in Model Development

Model framework

The underlying structure for modeling calf growth is prediction of nutrient requirements and estimation of nutrient supply using the 2001 Dairy NRC calf sub-model (NRC, 2001). This model predicts BW gain allowed by metabolizable energy (**ME-gain**) supply and also BW gain allowed by supply of apparently digested protein (**ADP-gain**). The lesser of ME-gain and ADP-gain is the expected BW gain for a calf at a given point in time using feeds and environment provided to the model.

Prediction of BW gain at a given day was expanded to predict daily growth from 3 to 112 days of age. A calf is assumed to weigh 42 kg at 3 days of age, although this may be adjusted by the user. Then, ME-gain and ADP-gain are predicted using the 2001 dairy sub-model. Then, BW on day 4 is calculated as day 3 BW plus the lesser of ME-gain or ADP-gain on day 3. The process is repeated for day 4 to day 112, resulting in a BW growth curve. The model calculates feed intake, so feed costs provided to the model allow calculation of total feed costs and efficiencies of growth. Daily intake of liquid (milk or CMR) is entered by the user. Daily dry feed intake (**DFi**) from concentrates and forages is predicted by the model using inputs for ages at which feeds are offered and any upper limits on voluntary intake.

The initial growth model based on the 2001 Dairy calf sub-model over-predicted growth of calves, particularly in the two months of life. We attempted to improve prediction of nutrient supply by adjusting digestibility of liquids, ME values of calf starters, and improved predictions of DFi.

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Nutrient supply models generally ignore the maturation of intestinal digestibility with advancing age (e.g., NRC, 2001). However, several studies have documented effects of age on digestibility of nutrients in liquid feed for preweaned dairy calves. For example, Terosky et al. (1997) reported that N digestibility in calves fed milk replacers containing whey or skim milk proteins increased from approximately 70% to 90% from 2 to 8 wk of age. Others reported similar increases with advancing age, generally concluding that digestibility increases to approximately 3 wk (Arieli et al., 1995; Terosky et al., 1997; NRC, 2001) or 5 wk (Guilloteau et al., 2009) of age. Recently, Quigley et al. (2021b) reported results of a meta-analysis that determined effects of age on digestibility on liquid feeds in calves prior to weaning. Change in DM digestibility with advancing age is in Figure 1. Models of nutrient supply from milk or milk replacer were adjusted in the updated model using equations from Quigley et al. (2021b) for DM, N, and fat and actose digestibility. These adjustments to the base model reduce BW gain in the first 30 days of life, particularly when calves are fed large amounts of CMR.

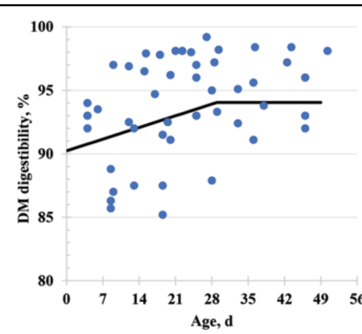

Figure 1. Change in digestibility of DM in calf milk replacers in calves from 3 to 50 days of age. From: Quigley et al. 2021b.

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A critical factor affecting growth of calves during the first 4 months of life is their ability to digest nutrients from dry feed. Prior to initiation of rumen development, digestion of fibrous feeds is extremely limited in young calves as digestibility of NDF in calves prior to about 8 weeks of age is quite low (Quigley et al., 2019a, b). Further, digestion of starch is limited for the first six weeks or so of life (reviewed in Quigley et al., 2019a); therefore, the calf's ability to extract ME from starters is clearly less prior to significant rumen development. The 2001 Dairy NRC calf sub-model ignores effects of rumen development on calculation of ME from dry feed. This results in an over-estimation of energy available to the calf. Energy limits growth in most scenarios, so this over-estimate of ME supply artificially increases growth predictions. Recently, we published a comprehensive review of factors affecting changing digestion in calf starters (Quigley et al. 2019a, b). We reported that intake of non-fiber carbohydrate (NFCi) is the key driver in hanging nutrient total tract nutrient digestion in calves to 4 months of age. Early in life, digestion of carbohydrates is limited; calculation of calf starter ME indicated that for the first few weeks of life, calves extracted only 40-60% of the energy in starters.

Thus, calf performance is over-estimated.

We also reported that cumulative NFCi rather than NFCi at a given point in time (Quigley et al., 2019b). This is logical, as NFCi is associated with rumen development, and cumulative NFCi would be more highly associated with total rumen development rather than NFCi on a given day. We found that when cumulative NFCi reached 15 kg, the ME in calf starters calculated using measured digestibility values were similar to those predicted by the 2001 Dairy NRC. Incorporating this adjustment into predictions of calf growth dramatically improves predictions of growth in calves to 4 months of age.

The ME values of concentrates and forages are adjusted by using adjustments in Quigley et al. (2019b) based on cumulative NFCi. The model determines daily NFCi and adjusts concentrate and forage ME. Result of this adjustment is reduction of ME supply and reduced rate of gain, particularly prior to weaning. High forage diets or starters containing more NDF also reduce ME supply and reduce BW gain.

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Predictions of dry feed intake in calves less than about 4 months are quite limited. Tedeschi and Fox (2009) predicted intake in Holstein calves to 200 d fed a diet of milk and ad libitum forage to simulate conditions of beef calves. Silva et al. (2019) reported two non-linear equations to predict calf starter intake in Brazilian Holstein and Holstein × Gyr calves to 64 d of age. Separate models were developed for calves fed more or less than 5 L of milk per day. Predictions did not follow calves after weaning, nor did equations accurately predict intake when equations were used in data from calves in the U.S. (unpublished data). Also, the 2001 Dairy NRC did not predict DFi in calves, but assumed that calves would consume sufficient ME from dry feed to meet ME requirements after ME intake from milk or milk replacer was considered.

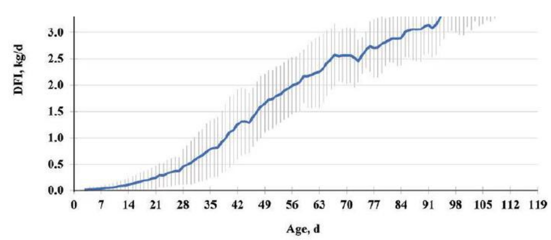


Figure 2. Dry feed intake (calf starter and forage) in calves from 3 to 114 d of age, kilograms per day. From: Quigley et al., 2021.

Recently, we developed several linear and non-linear equations to predict dry feed intake in calves from zero to four months of age under various feeding conditions, including high and low levels of milk feeding, ages at weaning, composition of starter, and inclusion of forage (Quigley et al., 2021a). The data set used in model development contained more than 60,000 individual daily observations of intake from 1,235 Holstein calves collected from 30 experiments at our research stations in the United States and Europe. The simplest non-linear equation was $1.4362 \times e^{[(-4.6646 + 0.5234 \times \text{MEgap}) \times \text{EXP}(-0.0361 \times \text{Age})]} + 0.0025 \times \text{Age} \times \text{MEgap}$ ($R^2 = 0.92$, concordance correlation coefficient = 0.96, and mean square error of prediction = 0.11 kg); where MEgap (Mcal/d) = difference of daily metabolizable energy (ME) requirement and ME intake from milk replacer; Age = age of calf (d) from 3 to 114. The ME requirement was based on 2001 Dairy NRC models.

Use of this updated DFI prediction equation increased the accuracy and precision of growth predictions in the model and made growth predictions more sensitive to intake of liquid (which reduces DFi and slows rumen development).

Application

We adjusted the 2001 Dairy calf sub-model with updated models of DFI and feed digestibility to predict calf performance to 4 months of age. Equations to predict DFi, CMR digestion and ME content of dry feed were built into a growth prediction engine for calves from 0 to 4 months of age, using Microsoft Excel. The application is called “GPS LITE” for “Growth Prediction System LITE”. Inputs include calf birth BW, feed composition, liquid feeding program, ages at which feeds are offered, and limitations (maximum amounts of feeds offered). The program calculates DFi and digestibility of nutrients from CMR and dry feed to calculate ME and ADP supply, then estimates growth for each using requirement equations from the 2001 Dairy NRC calf sub-model. Average daily gain using the minimum of ME-allowable and ADP-allowable gain is added to the BW on a given day to calculate change in BW from zero to four months of age.

An example of the model is in Figure 3. In this example, inputs to the model are in yellow highlighted cells. Calves are offered a CMR containing 24% CP and 17% fat from day 3 of age. Starter is offered from day 3, Grower feed from day 57 and forage (grass hay containing 8% CP and 60% NDF) is offered from day 42. Maximum offered is set to 99 kg, meaning that there is no maximum intake. Forage is offered for ad libitum consumption. The Liquid feeding program includes offering calves 480 g of CMR solids per day to d 7, then 1,200 g/d to d 42 and 800 g/d from day 43 to weaning on d 49.

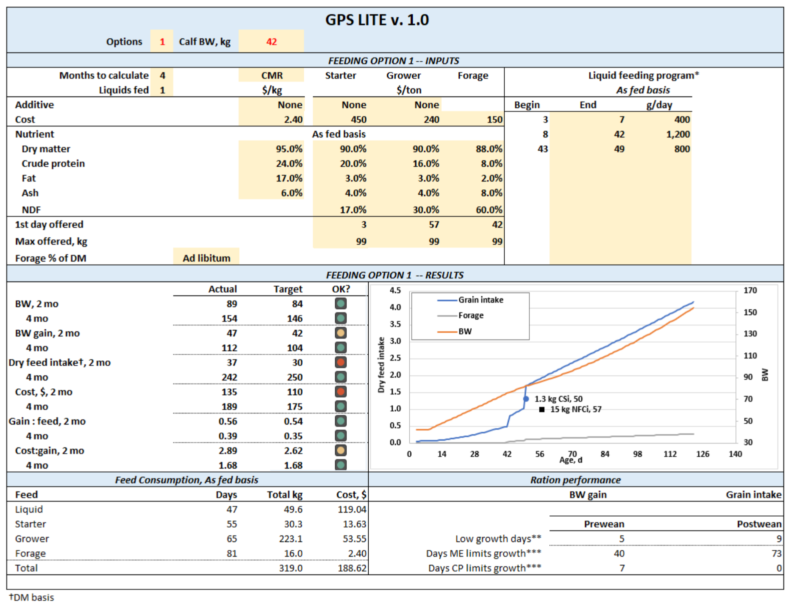


Figure 3. Model to predict growth of calves from 0 to four months of age.

Results are presented in the middle section of the spreadsheet. Predicted growth, intake, cost, and efficiency statistics are reported at two and four months and compared to targets based on doubling birth BW by two months of age and growth of 1 kg/d from two to four months. Targets for costs are based on an optimal growth scenario previously determined. Total intake and intake of each feed are reported in the bottom left quadrant of the results worksheet.

The graph in the middle section of the Worksheet displays changes in BW and intake of concentrates and forage. Also, predicted ages at which calves consume 15 kg of NFCi and 1.3 kg of DFi are reported. Critical value of 15 kg of NFCi is based on data from Quigley et al. (2019a, b) and 1.3 kg of DFi is based on a meta-analysis conducted as part of the 2021 Nutrient Requirements of Dairy Cattle (2021 NASEM) wherein the age at which contribution of microbial N to total abomasal N reached levels similar to those of adult cattle was determined as an indicator of maturing rumen function. These two statistics provide a reasonable indication of the age at which calves will be ready to be weaned– i.e., the age at which calves will not experience low growth prior to or after weaning.

In this example, calves reach the two targets at 50 and 57 days, respectively. Because calves are weaned at 49 days of age, the number of "low growth" days is higher than optimal. We defined "low growth" days as <400 g of ADG/d preweaning and <700 g/d postweaning. Though data are limited, we believe that calves experience low ADG experience increased stress which may predispose them to disease. Calves experienced a total of 14 low growth days in this scenario, primarily due to a short weaning phase (7 days), and high amounts of milk consumed. This effectively reduced NFCi and rumen development, consequently reducing digestibility of nutrients and ME available from dry feed.

The liquid feeding program was adjusted slightly to reduce the number of low growth days (Figure 4). The amount of CMR offered during the first week was increased from 450 to 700 g/d, which eliminated the preweaning low growth days. To eliminate the low growth days postweaning (which occurred immediately after weaning), the weaning age was increased from 49 to 60 days, with a longer weaning transition and the amount of CMR offered was reduced from 800 to 700 g/d. This change effectively resulted in increased DFi and NFCi so that calves were fully prepared for weaning. Statistics in the graph in Figure 4) show that ages at which calves were prepared for weaning were 55 and 60 days.

Cost of a feeding program is calculated as the sum of daily intakes of each feed and totals calculated at 2 and 4 mo of age. Cost targets are initially set according to a moderate CMR feeding program (700 g of solids/d) with weaning at 60 d of age and predicted starter intake in the program. These inputs may be adjusted by the user. Efficiency of growth (gain to feed ratio) and cost per unit of BW gain are calculated. Efficiency targets are also calculated from gain and intake (cost) targets.

GPS LITE v. 1.0

Options 1 Calf BW, kg 42

FEEDING OPTION 1 -- INPUTS

Months to calculate 4
Liquids fed 1

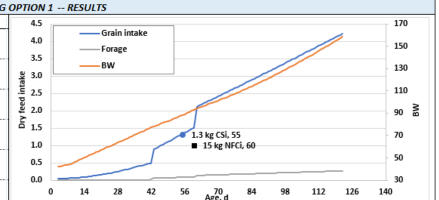
	CMR	Starter	Grower	Forage
	$/kg	$/ton		
Additive	None	None	None	
Cost	2.40	450	240	150
Nutrient		As fed basis		
Dry matter	95.0%	90.0%	90.0%	88.0%
Crude protein	24.0%	20.0%	16.0%	8.0%
Fat	17.0%	3.0%	3.0%	2.0%
Ash	6.0%	4.0%	4.0%	8.0%
NDF		17.0%	30.0%	60.0%
1st day offered		3	57	42
Max offered, kg		99	99	99
Forage % of DM	Ad libitum			

Liquid feeding program*
As fed basis

Begin	End	g/day
3	7	700
8	42	1,200
43	60	700

FEEDING OPTION 1 -- RESULTS

	Actual	Target	OK?
BW, 2 mo	93	84	
4 mo	159	146	
BW gain, 2 mo	51	42	
4 mo	117	104	
Dry feed intake†, 2 mo	31	30	
4 mo	239	250	
Cost, $, 2 mo	153	110	
4 mo	207	175	
Gain : feed, 2 mo	0.61	0.49	
4 mo	0.40	0.34	
Cost:gain, 2 mo	2.99	2.62	
4 mo	1.78	1.68	



Feed Consumption, As fed basis

Feed	Days	Total kg	Cost, $
Liquid	58	58.1	139.44
Starter	55	26.7	12.03
Grower	65	223.5	53.64
Forage	81	15.8	2.36
Total		324.1	207.48

Ration performance

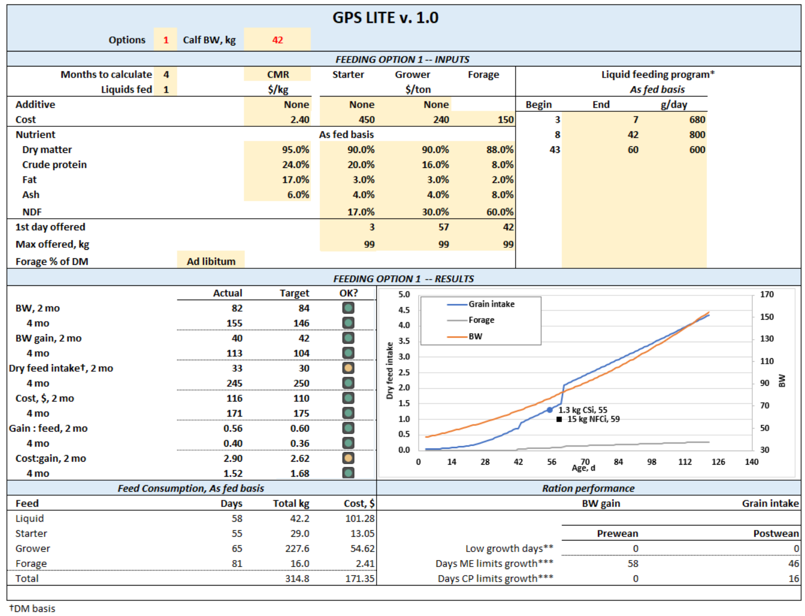
	BW gain	Grain intake
	Prewean	Postwean
Low growth days**	0	0
Days ME limits growth***	53	62
Days CP limits growth***	5	0

†DM basis

Figure 4. Model to predict growth of calves from 0 to four months of age.

While scenario 2 reduces the months of age. number of low growth days, total cost, and cost per unit of number of low growth days, total cost, and cost per unit of BW gain are increased to the point at which they exceed targets by greater than about 10 to 15% (yellow and red traffic lights). Using an iterative process, it is possible to develop a third scenario that achieves the goal of zero low growth days while maintaining or reducing costs of the overall program.

In scenario 3, the amount of CMR was reduced, though age at weaning was maintained at 60 d, based on the statistics in the graph (Figure 5).



GPS LITE v. 1.0

Options 1 Calf BW, kg 42

FEEDING OPTION 1 -- INPUTS

Months to calculate 4 / Liquids fed 1	CMR $/kg	Starter	Grower	Forage
		$/ton		
Additive	None	None	None	
Cost	2.40	450	240	150
Nutrient		As fed basis		
Dry matter	95.0%	90.0%	90.0%	88.0%
Crude protein	24.0%	20.0%	16.0%	8.0%
Fat	17.0%	3.0%	3.0%	2.0%
Ash	6.0%	4.0%	4.0%	8.0%
NDF		17.0%	30.0%	60.0%
1st day offered		3	57	42
Max offered, kg		99	99	99
Forage % of DM	Ad libitum			

Liquid feeding program*
As fed basis

Begin	End	g/day
3	7	680
8	42	800
43	60	600

FEEDING OPTION 1 -- RESULTS

	Actual	Target	OK?
BW, 2 mo	82	84	
4 mo	155	146	
BW gain, 2 mo	40	42	
4 mo	113	104	
Dry feed intake†, 2 mo	33	30	
4 mo	245	250	
Cost, $, 2 mo	116	110	
4 mo	171	175	
Gain : feed, 2 mo	0.56	0.60	
4 mo	0.40	0.36	
Cost:gain, 2 mo	2.90	2.62	
4 mo	1.52	1.68	

Feed Consumption, As fed basis

Feed	Days	Total kg	Cost, $
Liquid	58	42.2	101.28
Starter	55	29.0	13.05
Grower	65	227.6	54.62
Forage	81	16.0	2.41
Total		314.8	171.35

Ration performance

	BW gain	Grain intake
	Prewean	Postwean
Low growth days**	0	0
Days ME limits growth***	58	46
Days CP limits growth***	0	16

†DM basis

Figure 5. Model to predict growth of calves from 0 to four months of age.

Comparison of the three scenarios at two and four months of age is in Table 1. Total intake was generally similar at 2 and 4 mo of age, though the costs varied significantly, both at 2 and 4 mo of age. Calves fed scenario 2 (greatest amount of CMR) gain more BW by 2 mo of age, but there was less of a difference by 4 mo of age due to lower post-weaning growth. Calves in scenario 3 had greatest post-weaning BW gain greater intake and higher dry feed ME due to earlier DFi. The net result of these comparisons is that the most efficient scenario is #3, though feeding large amounts of CMR (scenario 2) results in greatest ending BW.

Summary

Providing farmers with useful and actionable feeding and management recommendations based on sound science and research data will assist them to make reasoned decisions when actual on-farm data measurement is lacking. Simulation of growth can provide reasonable estimates of calf performance while simultaneously providing important statistics from which decisions can be made. Our approach provides farmers with reasonable estimates of growth and allows users to evaluate different feeding programs to meet on-farm goals.

Item	Scenario 1	Scenario 2	Scenario 3
Total CMR, kg	50	58	42
Low growth days	14	0	0
Dry feed intake, kg			
2 mo	37	31	33
4 mo	242	239	245
Cost, $			
2 mo	135	153	116
4 mo	189	207	171
BW gain, kg			
2 mo	47	51	40
4 mo	112	117	113
G : F, kg/kg			
2 mo	0.56	0.61	0.56
4 mo	0.39	0.40	0.40
Cost/gain, $/kg			
2 mo	2.89	2.99	2.90
4 mo	1.68	1.78	1.52

Table 1. Comparison of two management strategies for calves to 4 months of age.

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