Early Life Management and Long-Term Productivity of Dairy Calves

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Overview of today's talk

- Introduction
- Discuss implications of colostrum
- Briefly discuss nutrient requirements of calves
- Emerging data about pre-weaning nutrition and future productivity
- Summary

Research and Practical Questions:

Does early life nutrition and management affect life-time productivity?

Does "programming" occur in neonatal dairy calves?

Is this the "permanent environmental effect" discussed by geneticists?

If so what factors are responsible?

How do we know? What should we be looking for?

Failure of Passive Transfer Reduces Long Term Performance

- **Calves with FPT:**
  - **Delayed time to first calving (Can Vet J., 1986, 50:314)**
  - **Decreased average daily gain to 180 days (J. Dairy Sci., 1988, 71:1283) – implied that colostrum Ig's helped avoid immune response**
  - **Decreased milk and fat production at first lactation (J. Dairy Sci., 1989, 72:552)**
    - **for each unit of serum IgG > 12 mg/ml there was a 18 lb increase in ME milk**

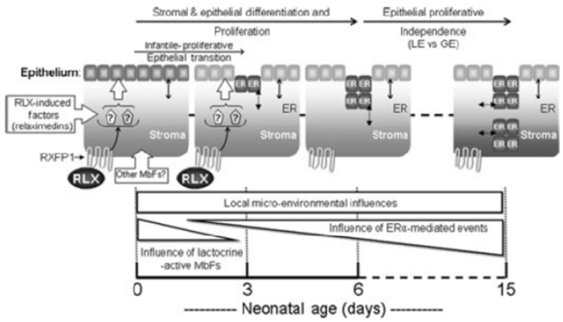
Colostrum is the foundation for functional change

Compounds in colostrum that can affect development:

Ig's – Immune system,
IGF-I – local gut effects
IGF-II – local gut effects
Lactoferrin – local immunity efffect in gut
Prolactin – good question – might be a candidate for calves
Insulin – local gut effects
Essential and Non-Essential Amino acids
Fat – wide profile of fatty acids - ????
Leptin – could affect the hypothalamic pituitary axis
Relaxin – pig, humans, dogs – impacts reproductive development

Relatively new concept related to the topic of epigenetic programming in neonates:

- Lactocrine hypothesis (Bartol, Wiley and Bagnell, 2009)
  - maternal programming extended beyond the uterine environment through ingestion of milk-borne morphological factors
  - milk in this case can include colostrum
  - In pigs, maternal Relaxin from milk stimulates development and differentiation of the uterus of the offspring by mediating the effect of estrogen on differentiation of stroma and epithelial cells and then proliferation



(Bartol, Wiley and Bagnell, 2008)

Agway Field Study – Western NY

- **~400 calves were fed three different milk replacers at two intake levels**
- **Followed calves through breeding**
- **Post study evaluations clearly indicated Ig status was most important variable in predicting growth and feed efficiency**
- **Calves with FPT (< 5.5 mg/dl plasma protein at 48 hr) had approximately 50% less feed efficiency**
  - **No differences in DMI of milk replacer or calf treatments**

Inadequate Colostrum Intake Reduces Long Term Performance

Effects of Colostrum Ingestion on Lactational Performance, Prof. Anim. Scientist, 2005

Brown Swiss calves were fed 2 L or 4 L of colostrum and colostrum over another 6 to 8 feedings

	2 L	4 L
n	**37**	**31**
Daily gain, lb/d	**1.76**	**2.2**
Age at conception, mo	**14.0**	**13.5**
Survival through 2nd lact.	**75.3**	**87.1**
Milk yield through 2nd lact., lb	**35,297**	**37,558**

Pro-active Calf program goals:

1. Double birth weight by 56 days (minimum goal)

   90 lb birth weight → 180 lb @56 days

2. Calf mortality less than 5%
3. Calf morbidity (treatments) less than 10%

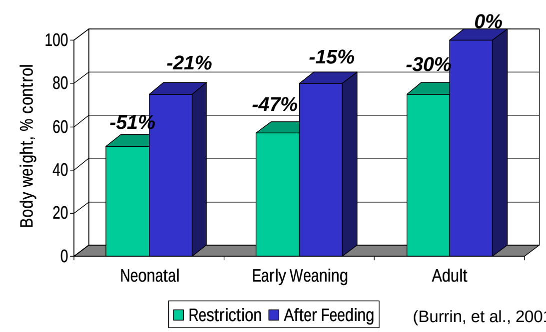
Why do this?

Capture feed efficiency of early life
Achieve breeding weight at an earlier age
Potentially reduce AFC/increase BW@calving
Increase potential for Internal Herd Growth
Potentially increase milk yield and herd life

Nutrient Requirements and Compensatory Growth

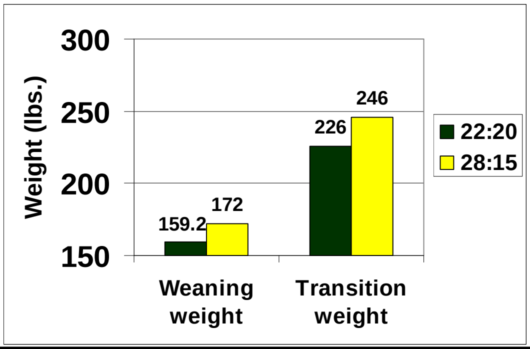
- Many producers believe that calves can “compensate” from early life nutrient restrictions
- Most neonates, including pre-weaned calves do not have compensatory gain mechanisms
  - Effects of early life nutrient restriction are difficult to overcome (immune system and normal growth)

Effect of Malnutrition (50% normal intake for three weeks) and Refeeding (normal intake) During Different Stages of Life on Bodyweight in Pigs



(Burrin, et al., 2001)

Effect of feeding isocaloric amounts of 22:20 CP:Fat and 28:15 CP:Fat milk replacers on growth under identical management – data of Tikofsky et al.



Environmental and Stress Effects on Maintenance Requirements

Calves less than 21 days of age are comfortable between 60 to 81°F

In New York, we spend at least 160 days/year below the lower critical temperature.

The additional heat increment required to maintain core body temperature below 60 °F is approximately 0.022 Mcal/kg0.75/°C, especially for calves < 21 d.

For calves > 21 days of age the lower critical temperature is 43°F.

This approach was adopted by the NRC, 2001.

Environmental and Stress Effects on Maintenance Requirements

Based on Arieli et al. (1995) an additional adjustment of 0.03 Mcal ME/kg$^{0.75}$ might be warranted for pre-weaned calves that have been are adapting to any stressor(s) for at least 14 days after the initial stress.

Stress can be defined as transportation, significant alteration in temperature or a social and dietary change

Equivalent to 0.5 to 0.6 Mcal ME/d for the average calf (~ 0.26 lb of DM/d)

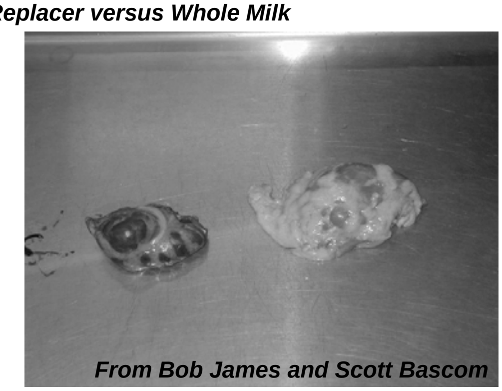
Amount of Milk Replacer/Milk Dry Matter Required to Meet Maintenance Requirements

	Temperature, °F						
	68	50	32	15	5	-5	-20
Bodyweight, lb							
60	0.6	0.8	0.9	1.0	1.1	1.2	1.4
80	0.8	0.9	1.1	1.3	1.4	1.5	1.7
100	1.0	1.1	1.3	1.6	1.7	1.8	2.0
120	1.1	1.3	1.5	1.7	1.9	2.0	2.3

Amount of Milk Replacer/Milk Dry Matter Required to Meet Maintenance Requirements and Gain One Pound per Day

	Temperature						
	68	50	32	15	5	-5	-20
Bodyweight, lb							
60	1.1	1.2	1.4	1.5	1.6	1.7	1.8
80	1.2	1.4	1.6	1.7	1.9	2.0	2.2
100	1.4	1.6	1.8	2.0	2.2	2.3	2.5
120	1.6	1.8	2.1	2.2	2.5	2.6	2.8

Kidney Fat – Jersey Calves Fed 20:20 Milk Replacer versus Whole Milk



Nutrient Requirements

- **In the last 10 years we have made remarkable progress in understanding the nutrient requirements of calves and heifers (body composition data on over 400 calves and heifers from Cornell, Univ. of Illinois and Virginia Tech)**
- **Further, we have learned how to manipulate the composition of gain.**

Updated Nutrient Requirements of a 100 lb Calf Under Thermoneutral Conditions

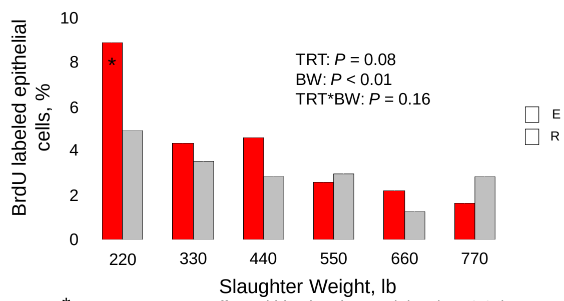
Rate of gain, lb/d	ME[a], mcal/d	DMI, lb/d	ADP, g/d	CP, g/d	CP, % DM
0.44	**2.35**	**1.12**	**87**	**94**	**18.0**
0.88	**2.89**	**1.40**	**140**	**150**	**23.4**
1.32	**3.48**	**1.67**	**193**	**207**	**26.6**
1.76	**4.13**	**1.98**	**235**	**253**	**27.5**
2.20	**4.80**	**2.39**	**286**	**307**	**28.7**

Van Amburgh and Drackley, 2005

Effects of Neonatal Nutrition on Productivity and Mammary Development

- More data is emerging that suggests early life nutrient intake has long term impacts on productivity
- Mechanism is not completely understood
- Forces us to think about imprinting, cell programming, stem cells, and other programming events

Epithelial Cell Proliferation



*Denotes treatment effect within slaughter weight. ($P < 0.05$)

Meyer et al., 2006

Data that got me excited……

Study	Response
Bar-Peled et al., 1998	+ 998 lb
Foldager and Krohn, 1994	3,092 lb
Foldager et al., 1997	1,143 lb
Mean response	+ 1,743 lb

Suckling/milk feeding studies – 1.6 to 2.3 gallons versus ~ 1 gallon milk

Miner Institute, NY and Zenoh (Japan)

1.3 versus 2 to 2.2 lb of milk replacer powder per day

At 200 DIM, calves fed more milk replacer produced 1,761 lb more milk

(Ballard et al. JDS Abst. 2005)

Univ of Illinois- 1.25 vs 2.2 lb Dry Matter Milk Replacer per day for 42 days

Variable	Control	Enhanced
Age at calving (mo)	24.6	25.4
Calving BW (lb)	1,276	1,278
Milk yield (lb)	19,844	21,687
Difference		1,843

Conducted over two years – some year interactions – 3,000 lb response one yr, 800 lb response 2nd yr

Drackley et al., JDS abstr. 2007

Michigan State Study

- **Moderate feeding vs Intensified program**
- **Followed heifers up to 150 DIM**
- **Intensive fed heifers calved ~ 22 days earlier**
  - **Produced 1,100 lb more milk in first lactation (Based on projected ME 305 milk) not significant**
- **Concluded intensified feeding with earlier calving and milk difference was economically advantageous**

JDS 2006 Abstr 89:438

Univ. of Minnesota Study - (Chester-Jones et al., 2009)

- Calves fed 1.25 vs 2.2 lb/d day milk replacer DM - weaned by 49 days
- Followed heifers through to 1st Lactation
- Heifers fed 2.2 lb/d for 49 days:
  - Produce ~1,800 lb more milk in first lactation – not significant

Effects of feeding ad-lib milk vs ad-lib milk replacer with or without additional protein from 150 to 300 days of age

- Milk replacer (23% CP: 12%Fat – containing soy protein) vs whole milk to weaning
- Basal diet post weaning was low in protein (< 14%)
- From 150 to 300 days of age half of each group provided 2% additional protein (fish meal)
- Calves fed whole milk and supplemented with 2% added protein produced ~ 1,613 lb more milk in first lactation ($P < 0.007$)

Moallem et al., 2010

Milk production response where calves were allowed to consume ~50% more nutrients than standard feeding rate prior to weaning from liquid feed

Study	Milk response, lb
Foldager and Krohn, 1994	3,092
Bar-Peled et al., 1998	998
Foldager et al., 1997	1,143
Ballard et al., 2005 (@ 200 DIM)	1,543
Shamay et al., 2005 (added post-weaning protein)	2,162
Rincker et al., 2006 (proj. 305@ 150 DIM)	1,100
Drackley et al., 2007	1,841
Chester-Jones et al., 2009	1,800
Morrison et al., 2009	0
Moallem et al., 2010 (added post-weaning protein)	1,613

Using a Genetic Evaluation Tool to Investigate the Milk Yield Response to Early Life Nutritional Management

Application of the Cornell Test Day Model for Calf Growth and Long-term Performance

Mike Van Amburgh, Fernando Soberon, Emiliano Raffrenato, Robert Everett

Test Day Model

- The TDM is a method for evaluating daily production of milk, fat, protein and SCC more accurately than can be done by using 305-d mature equivalent lactations
- Effects of test day, age, stage of lactation, pregnancy, and month of calving are estimated from the individual and the herd mates and residuals (differences from the grand mean) are generated

Test Day Model & Cornell Dairy Data

- We analyzed the lactation data with the Test Day Model (TDM) – allowed us to control for year, season, genetics and management variation over the period of measurements
- Generated TDM residuals for the lactation and then regressed the lactation data on calf growth variables
- Same mathematical procedure used to estimate PTA, heritability, other production traits

The Cornell Dairy Herd

- We started feeding for > 2.0 lb pre-weaning ADG in 1998
- We have over 1,400 weaning weights from this data
- We have ~ 1,200 finished first lactations from this data
- We wondered if any calf measurement had any relationship to first lactation milk yield

Traits Evaluated

- Birth weight
- Weaning weight
- Average daily gain until weaning
- Gain in hip height
- Gain in wither height
- Prepubertal ADG
- Intake over maintenance from milk replacer

Cornell Herd - Effect of Pre-Weaning Daily Gain on Milk Yield

- The range in growth rate in the data set was 0.23 to 3.5 lb per day to weaning
- Why the range in growth if the program is the same year around?
- This range has caused some to question our data – we turned it into a learning opportunity

Effects of Pre-Weaning Gain and other effects on Milk Yield

- Year effects were worth 2,000 lb of milk in the first lactation
- We're not sure what that means – similar effect in Univ. of Illinois data – but we now have a clue!
- Colostrum related, nutrient intake, housing, programming, previous generation effect, imprinting or epigenetics
- Day and month were not significant

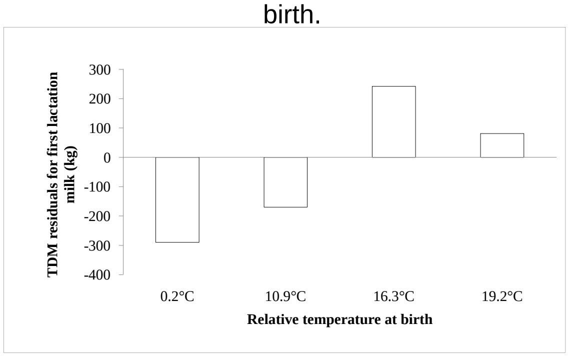
Cornell Herd - Effect of Pre-Weaning Daily Gain on Milk Yield

- Hip height and hip height change also carried some positive effects on milk yield
  - probably correlated with the ADG effect

305 day Milk and ADG in Cornell Herd

- We used the 305d milk yield in a more traditional analyses. The model used accounted for year of calving.
- Year of calving was significant (P < 0.001)
- ADG was also significant (P < 0.005)
- For every 1 lb of ADG prior to weaning, milk yield increased 706 lb in first lactation

Test Day Model residual milk by temperature at birth.



Soberon et al. 2009 (Abstr)

Effect of Nutrient Intake from Milk Replacer on Milk Yield over 3 lactations – Cornell Herd

Lactation	# of animals	Predicted difference in milk yield per 2.2 lbs of ADG, lb	*P* value
1st	1244	1,871	< 0.01
2nd	826	1,957	< 0.01
3rd	450	106	0.91
1st to 3rd	450	5,023	< 0.01

Soberon et al. JDS 2011, submitted

Effect of Nutrient Intake from Milk Replacer on Milk Yield over 3 lactations – Cornell Herd

Lactation	# of animals	Pred. diff. in milk yield for each Mcal over maint., lb	*P* value
1st	1244	518	< 0.01
2nd	826	238	0.26
3rd	450	774	<0.01
1st to 3rd	450	1,990	<0.01

Soberon et al. JDS 2011, submitted

Cornell Herd - Effect of Pre-Weaning Daily Gain on Milk Yield

- In this evaluation, 22% of the variation in first lactation milk yield was explained by pre-weaning growth rate up to 42 - 49 days of age

What this means

- The effect of growth rate and thus nutrient intake prior to weaning had a more direct and significant effect on milk yield than any genetic selection for production
- Genetic selection yields ~ 150 – 300 lb milk per lactation
- Calf nutrition and management can yield 4 to 8 times more than genetic selection per lactation

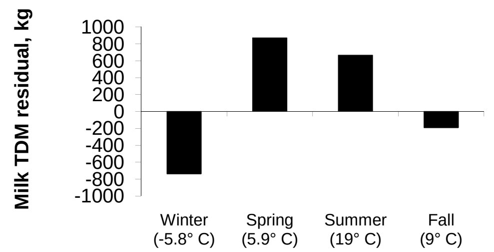
What this might mean

- When we feed for more nutrient supply above maintenance, we are actually setting the calf up to be a better lifetime milk producer
- Since "stayability" or herd life is directly correlated to milk production, the implication is we might enhance herd life through better early life nutrition.

The Long-Term Effect of Early Life Nutrient Intake in the Cornell Herd

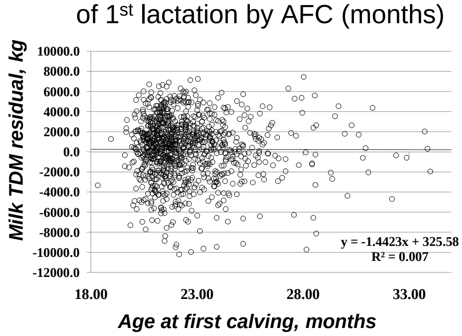
- The TDM residuals are standardized which allows us to add them
- For the 450 animals with 3 lactations, the lifetime effect of enhanced ADG was 5,023 lb of milk for every 2.2 lb of daily ADG prior to weaning
- Or 1,990 lb milk for every Mcal of Intake Energy over maintenance from liquid feed

Commercial herd: TDM 1st lactation milk residuals (kg) by season of birth – 623 lactations



Raffrenato et al. EAAP 2009

Commercial herd: TDM milk residuals (kg) of 1st lactation by AFC (months)



Commercial Dairy Farm

Lact.	N	Pred. diff. in milk yield / kg pre-weaning ADG, lb	*P*	Pred. diff in milk yield / kg ADG from weaning to breeding, lb*	*P*
1st	623	2,455	0.03	1,984	< 0.01
2nd	484	-1,159	0.49	3,374	< 0.01
3rd	271	2,850	0.18	2,330	0.16
1st – 3rd	271	2,834	0.51	9,327	< 0.01

*ADG from weaning to breeding had a coefficient of correlation of 0.94 with ADG from birth to breeding ($P < 0.01$).

Effect of Pre-pubertal Growth Rates on First Lactation Milk Yield – Foldager and Sejrsen, 1987

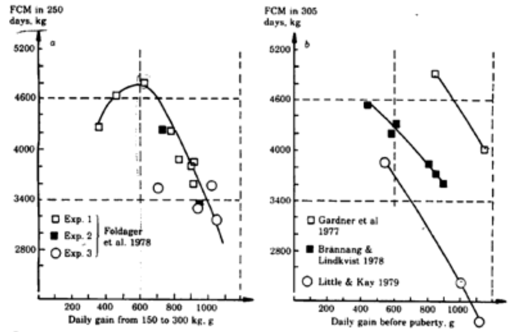


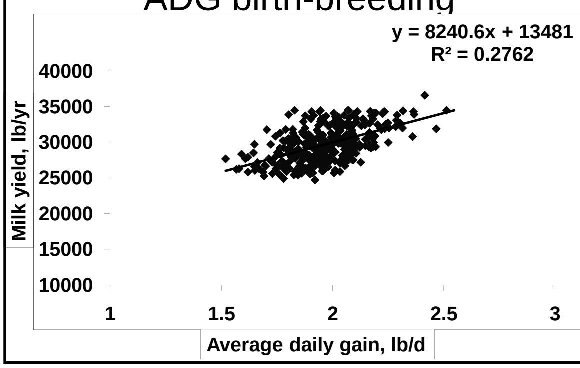
Figure 1. Milk production in first lactation in relation to daily gain before puberty (Foldager & Sejrsen, 1982)

305 Day Fat Corrected Milk vs Pre-Pubertal Body Growth Rate

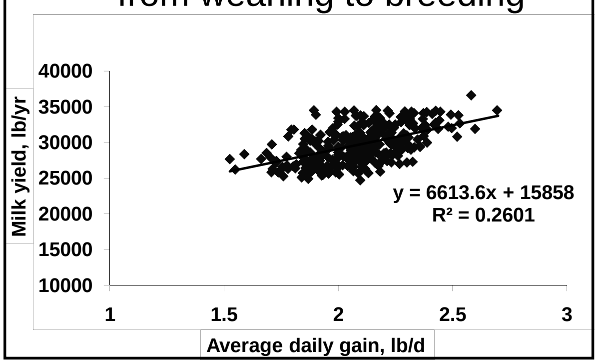
$R^2 = 0.07$

Van Amburgh et al. 1998

First lactation milk yield vs ADG birth-breeding



First lactation Milk Yield vs ADG from weaning to breeding



Cornell Analysis of Profit/Loss

- Based on heifer cost study conducted by Jason Karszes
- Cost of rearing heifer to calving was similar – calved ~ 3 mo earlier. Feed costs increased to offset time to calving.
- With NPV discount on milk income assuming 1,800 lb increase in first lactation and change in time to calving, profit increased $211
- Taking into account the change in inventory increased ROI from 0.8% to 7.4%

Economic Comparison of Conventional vs. Intensive Heifer Rearing Systems

Michael Overton, DVM, MPVM
The University of Georgia

Economic Analyses by Dr. Mike Overton

Net Results

(Initial Calf Value of $200)

Outputs:	Conventional System:	Accelerated System:
Calf investment cost at calving	225	223
Average age at first service	14.0	11.3
Average age at first calving	**24.7**	**22.0**
Average daily gain (lbs)	**1.52**	**1.98**
Total rearing cost/ heifer (incl. interest + initial value + repro culls)	**$ 1,706**	**$ 1,687**
Avg Cost/ Day	**$ 2.27**	**$ 2.52**
Additional milk value	**$ -**	**$ 170**
Net "cost"/ heifer	**$ 1,706**	**$ 1,517**

Economic Analyses by Dr. Mike Overton

- Based on the assumptions used in this model:

Net Results: (Intensive vs Conventional)		
Feed costs	$	74.29
Labor costs	$	(14.66)
Health/ vet med	$	(14.65)
Interest cost	$	(15.50)
Reproductive culls	$	(7.45)
Other costs	$	(20.36)
Total "dead calf" costs	$	(21.49)
Net Result (Savings):	**$**	**(19.81)**

- Add in value of additional milk - $170 – and the advantage for **Intensive Rearing ~ $190**

Mike Overton, AABP 2010

Summary of Early Nutrition Effects

- Nutrient intake in early life impacts lactation milk yield - all data are positive to neutral
- The mechanisms are not understood – but most likely a function of several factors
- The data very clearly demonstrate that early life management enhances the effect of genetic selection for milk yield.
- Bottom line – there is milk in early life colostrum and nutritional management

A Feeding and Weaning Strategy

- **1.5% BW dry matter from day 2 to 7**
- **2.0% BW dry matter from day 8 to 42 (this is a management and economic decision)**
- **On a subsequent day (43 for example) feed 50% of previous day intake (4 vs 8 qts) – feed in evening – longest interval and coldest time of day**
- **On day 50 remove all milk**
- **Calves should be consuming ~ 1.5 to 2 lb/d starter by then**

TAKING THE LONG VIEW: TREAT THEM NICE AS BABIES AND THEY WILL BE BETTER ADULTS

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INTRODUCTION

Discussing the topic of calves and calf management over the last 40 years traditionally involved dry cow management, colostrum, scours, rumen development and early weaning. In the last ten years, the concept of "intensified feeding or accelerated growth" has become a focus of discussion and during that time the concept has been applied to research programs and on farm in various ways. Much of this discussion involves differences in perspectives about how to best manage the nutrition and nutrient intake of the pre-weaned calf. There are teleological arguments for providing a greater supply of nutrients from milk or milk replacer, e.g. what would the dam provide, and there are also arguments for improving the welfare status of the animals by following the same concept (Jasper and Weary, 2002; de Paula Vieira et al., 2008). At the 15th American Dairy Science Association Discover Conference on Calves (Roanoke, VA) the overwhelming consensus of the participants was that we need to feed calves for a specific rate of daily gain, much higher than the traditional industry standards, and that is significant change in industry perspective.

Requirements - Maintenance

The calf has a requirement for maintenance and once maintenance requirements are met, growth can be achieved if enough nutrients and the proper balance of nutrients are provided to the calf. The nutrient requirements of the calf have been described in the current Nutrient Requirements of Dairy Cattle 7th edition (NRC, 2001) publication. The requirements can be easily actualized and are very useful for diagnosing the impact of temperature on the maintenance requirements of the calf through the computer program that accompanies the publication.

The maintenance requirements estimated by 2001 NRC appear to be excellent and reflect our field observations for overcoming negative energy balance brought about by cold stress conditions. Example requirements are demonstrated in Table 1 based on body weight and ambient temperature. The user needs to remember that these values are the basal requirements for energy to maintain core body temperature with no growth or with no wind or wet conditions, which would exacerbate the requirements. The long-term consequences of not altering these values will be discussed throughout the paper. Our recent data suggests there is a significant lifetime milk loss associated with not meeting these requirements appropriately.

For many years the National Animal Health Monitoring System (NAHMS) has published reports describing the morbidity and mortality of calves and heifers on representative U.S. dairy farms. In a recent report, pre-weaning death loss was reported at 8% (NAHMS, 2004), whereas the previous survey reported 11% (NAHMS, 1996). In a thorough review of calf management practices, Otterby and Linn (1981) indicted mortality was approximately 11.3%, which indicates we have not made much progress over the last 25 years. Also, a previous report indicated that sickness (or the percent of calves treated) ranged between 30 and 40% on most farms.

Table 1. The amount of milk replacer or milk dry matter required to meet the maintenance requirements of calves at varying temperatures. The calculations assume 2.45 Mcal ME per lb of dry matter.

	Temperature, degrees F						
	68	50	32	15	5	-5	-20
Bodyweight, lb							
60	0.6	0.8	0.9	1.0	1.1	1.2	1.4
80	0.8	0.9	1.1	1.3	1.4	1.5	1.7
100	1.0	1.1	1.3	1.6	1.7	1.8	2.0
120	1.1	1.3	1.5	1.7	1.9	2.0	2.3

A study by Godden et al. (2005) replicated the mortality and morbidity values from the NAHMS survey and their data suggested the outcome was a function of the amount and type of diet fed. In their study, calves were fed either batch pasteurized whole milk at approximately 1 gallon per day, or 1 lb of 20% CP, 20% fat milk replacer reconstituted at 12.5% solids. The length of the study encompassed all of the seasons. Calves fed the whole milk had significantly less death loss and treatments (Table 2) suggesting that the difference in nutrient intake, approximately 18% greater ME intake per day from whole milk compared to the milk replacer, had a profound impact on the survival and disease resistance of the calves. The bottom line is that calves provided

Table 2. Effect of feeding calves one gallon of pasteurized whole milk or one pound of 20:20 milk replacer on morbidity and mortality (Godden et al., 2005).

	Milk replacer treatment	Pasteurized whole milk treatment
N	215	223
Morbidity, % of calves		
All months	32.1	12.1
Winter	52.4	20.4
Summer	12.7	4.4
Mortality, % of calves		
All months	11.6	2.2
Winter	21.0	2.8
Summer	2.7	1.7

more nutrients had less death loss and that the morbidity and mortality observed on this study is consistent with the NAHMS data and suggests we need to do a better job managing cold stress and other stressors in calves. This should not be confused with the notion that milk replacer is not as good as whole milk. It demonstrates that adjustments need to be made when feeding any diet if the requirements of the calf change due to the environmental temperature or stress conditions.

Calves are born with about 4% body fat, of which about 50% can be mobilized and much of that is brown adipose tissue needed for thermogenesis. This gives the calf up to four days of fat reserves depending on the ambient conditions and once depleted, the calf has to rely on either dietary intake or body protein to generate heat and mount an immune response if nutrient intake is below maintenance requirements. This sets up a situation that encourages failure of the immune system unless additional calories from protein, carbohydrates and fat are provided. Body protein reserves are very low in neonatal calves and are not good sources of calories for maintaining body heat and mounting immune responses. An additional factor to be considered is what calves use to deposit body fat. Data from several studies demonstrate that calves cannot make fat from carbohydrate very effectively if at all, thus any increase in adiposity must be from dietary fat intake (Tikofsky et al. 2001; Joost et al., 2007). Thus, under cold stress conditions or situations where feed intake is compromised due to illness, the only way to provide greater calories and energy reserves is through the increased intake of dietary fat. Compared to most milk replacers, this is likely why calf managers see significant increases in calf performance when whole milk is fed, especially in cold weather conditions.

Energy and Protein Requirements

Prior to and since the release of the Nutrient Requirements for Dairy Cattle (NRC, 2001), new data were being developed and are now available that help us refine those predictions (Bartlett, 2001, Diaz et al., 2001, Tikofsky et al., 2001; Bascom et al., 2007; Blome et al., 2003; Brown et al, 2005; Meyer, 2004; Mills, 2009). Table 3 summarizes the current knowledge about the requirements for growth of the calf based on the body composition data derived since the 2001 NRC was published.

These values are consistent with the current publication (NRC, 2001), but have slightly lower energy requirements per unit of gain because the original equations were based on heavier veal type calves fed higher fat diets and depositing more fat per unit of weight gain. These predictions for energy requirements are consistent with dairy replacement calves being fed diets more typical of our system. The protein requirements are higher than the NRC (2001) publication because of updated data on the efficiency of use of absorbed protein. The 2001 NRC (NRC, 2001) calculations suggested that absorbed protein was used with an efficiency of 0.80, whereas our latest calculations suggest the efficiency is closer to 0.70, thus the protein requirements are at least 10 to 12% higher than the NRC (2001) predictions and very energy dependent e.g. the more energy they consume, the greater the potential protein synthesis, and the higher the protein requirement.

Table 3. The energy and crude protein requirements of calves from birth to weaning (Van Amburgh and Drackley, 2005)

Rate of gain, lb/d	Dry matter intake, lb/d	Metabolizable energy, Mcal/d	Crude protein, g/d	Crude protein, %DM
0.45	1.2	2.4	94	18.0
0.90	1.4	2.9	150	23.4
1.32	1.7	3.5	207	26.6
1.76	2.0	4.1	253	27.5
2.20	2.4	4.8	307	28.7

These requirements reinforce the idea that what the cow would normally provide to the calf is a more appropriate combination of protein and energy required by the calf. Thus, many milk replacers are not really replacing milk because they don't contain the same nutrient levels and they are rarely fed to equal the nutrient intake of whole milk. It further suggests that least cost milk replacer formulations should not be expected to provide much beyond maintenance energy supply and the feeding of such milk replacers at previously recommended levels might exacerbate the lack of immune system responsiveness and energy reserves needed in support of an illness event. Dietary fat levels will be dependent on the ambient temperatures. The body composition data would indicate that 15% fat is adequate when the calves are not under cold stress conditions, and that as temperatures decrease, fat needs to increase to offset the oxidation for thermogenesis. In addition, attention should be made to the inclusion of essential fatty acids in the diet of neonatal and weaned calves since it appears traditional calf diets have been deficient in essential fatty acids required for proper growth (Hill et al. 2009)

However, to further this idea that calves have "requirements" beyond those for growth and thus need enhanced nutrient intakes, data are available and emerging that suggest factors such as colostrum status and nutrient intake and growth rates up to at least 8 weeks of age have life-time effects that can be measured in the first lactation. Just like other neonates, it appears that early life events may serve as a catalyst for metabolic programming (or imprinting) generating epigenetic changes in the calves that will remain with them for their entire life, therefore "compensatory mechanisms" don't really exist for this stage of development.

It also suggests that we need to alter how we view this stage of development especially as it relates to future productivity. The concept and data to support it are still being developed, but there appears to be a positive relationship with early life nutrient intake.

EARLY DEVELOPMENT AND PRODUCTIVITY

Colostrum Status

To maximize calf survival and growth, plasma immunoglobulin (Ig) status and thus colostrum management is of utmost importance. This is obviously not a new concept and there are hundreds of papers describing the management and biology surrounding colostrum quality, yield and Ig absorption by the calf although some recent research in colostrum handling and management suggest we can still make improvements (Godden, 2008). A proper discussion of colostrum includes factors other than Ig and should include the myriad of other factors in colostrum that have shown to be beneficial to the calf. Factors like insulin, insulin I-like growth factor-I (IGF-I), maternal leukocytes, oligosaccharides, other growth factors and many other useful compounds are found in colostrum and are most likely very important in the response of the calf to ingestion of the secretion. Minimizing the bacterial load of colostrum is probably one of the major management concerns with many farms and is usually a factor not considered or analyzed for. Data demonstrate that the presence of bacteria in the gut prior to colostrum ingestion or in the colostrum reduces the uptake of Ig, thus increasing the incidence of failure of passive transfer (James et al. 1981, Godden, 2008). Thus excellent udder health and proper post-harvest colostrum handling is as important, or even more important than vaccination programs to prevent diseases.

Of interest for this paper are the studies that have described decreased growth rate and increased morbidity of calves with low serum immunoglobulin status (Nocek, et al., 1984; Robison et al., 1988) and some have even indicated that milk yield during first lactation can be affected (DeNise et al., 1989). Robison et al. (1988) indicated that calves with higher Ig status were able to inactivate pathogens prior to mounting a full immune response which allows them to maintain energy and nutrient utilization for growth, whereas calves with low Ig status must mount an immune response which causes nutrients to be diverted to defense mechanisms. How severe is this difference or for how long does it persist? The data of DeNise et al., (1989) demonstrated that for each unit of serum IgG concentration, measured at 24 to 48 hrs after colostrum feeding, above 12 mg/mL, there was an 18.7 pounds increase in mature equivalent milk. The implication is that calves with lower IgG concentration in serum were more susceptible to immune challenges which impacted long term performance. As with all longitudinal and epidemiological studies there are inconsistencies. Donovan et al. (1998) found indirect effects of colostrum status on growth and performance of calves, but concluded it was caused by increased morbidity and not a direct effect. The calculations of growth and feed efficiency should in many cases include the calves that were lost to study, thus providing a more applicable value.

A more recent study suggested that impact of serum Ig concentrations was not nearly as great as the DeNise et al. (1998) study, but did affect milk yield and survival through the second lactation (Faber et al., 2005). Brown Swiss calves were provided either 2 or 4 L of colostrum just after birth with some additional meals over a 4 day period. The calves were monitored after calving for two lactations. At the end of the second lactation three major observations were made, first there was a 30% increase in pre-pubertal growth rates based on colostrum feeding level, under identical feeding conditions. Second, there was a 16% increase in survival to the end of the second lactation of calves fed the four liters of colostrum. Finally, the surviving calves fed the 4 L of colostrum produced 2,263 lbs more milk by the end of the second lactation. Although somewhat subtle, these differences suggest that early life colostrum status was important for long-term productivity. If part of the mechanism is related to maintaining nutrient partitioning towards growth via high immunoglobulin status, then the concept of nutrient status should also demonstrate responses beyond the Ig status of the calf. This difference in growth rate has been observed in studies comparing colostrum with colostrum replacement. Calves fed colostrum replacer had nearly identical plasma IgG concentrations, but grew at a rate 30% less than the colostrum fed calves (Mowrey, 2001). This would indicate there are components of colostrum important for growth and feed efficiency independent of the Ig content and understanding which factors are important is an active area of research.

Nutrient status and long-term productivity

There are several studies in various animal species that demonstrate early life nutrient status has long-term developmental effects. For a more extensive discussion of this topic, a recent review of these concepts was conducted by Drackley (2005). Aside from the improvement in potential immune competency, there appears to be other factors that are impacted by early life nutrient status.

There are several published studies and studies in progress that have both directly and indirectly allowed us to evaluate milk yield from cattle that were allowed more nutrients up to eight weeks of age. The earliest of these studies investigated either the effect of suckling versus controlled intakes or ad-libitum feeding of calves from birth to 42 or 56 days of life (Foldager and Krohn, 1994; Bar-Peled et al, 1997; Foldager et al, 1997). In each of these studies, increased nutrient intake prior to 56 days of life resulted in increased milk yield during the first lactation that ranged from 1,000 to 3,000 additional pounds compared to more restricted fed calves during the same period (Table 4). Although they are suckling studies, milk is most likely not the factor of interest, but nutrient intake in general and this is demonstrated in the more recent data.

In the study conducted at Miner Institute, Ballard et al. (2005), reported that at 200 days in milk, the calves fed milk replacer at approximately twice normal feeding rates produced 1,543 pounds milk more than the calves that received one pound of milk replacer powder per day. Calving age in that study was not affected by treatment. Overall, averaging the studies, there is a 1,500 pound response to increasing nutrient intake prior to weaning for first lactation milk yield. The significant observation is that the effect of intake level needs to be accomplished through liquid feed intake.

The response in the studies of Shama et al. (2005) and Moallem et al. (2010) are sis significant, specifically because they suggests that milk replacer quality is important to achieve the milk response, as is protein status of the animal post weaning. In that study, the calves were fed a 23% CP, 12% fat milk replacer containing some soy protein or whole milk. Further, post-weaning the calves were fed similarly until 150 days of gain, and the diets were protein deficient (~13.5% CP). Starting at 150 days calves from both pre-weaning treatments were supplemented with 2% fish meal from 150 to 300 days of life. The calves allowed to consume the whole milk (ad libitum for 60 minutes) and supplemented with the additional protein produced approximately 1,700 pounds more milk in the first lactation indicating that the early life response could be muted by inadequate protein intake post-weaning.

Table 4. Milk production differences among treatments where calves were allowed to consume approximately 50% more nutrients than the standard feeding rate prior to weaning from liquid feed.

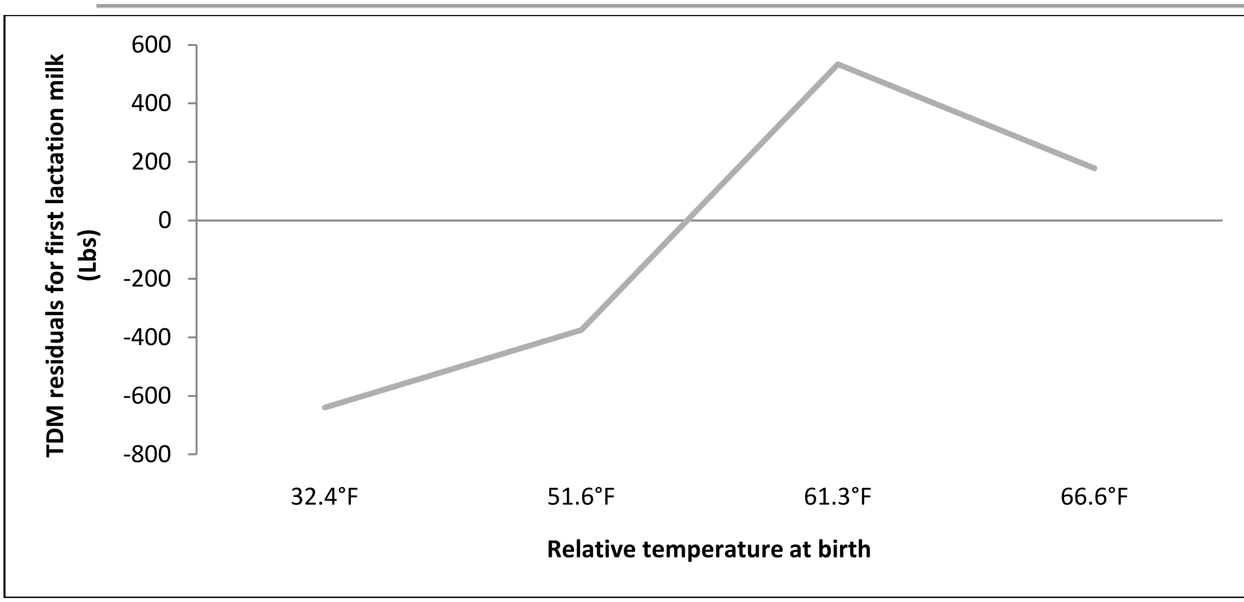
Study	Treatment Difference, lb
Foldager and Krohn, 1994	3,092
Bar-Peled et al., 1998	998
Foldager et al., 1997	1,143
Ballard et al., 2005 (@ 200 DIM)	1,543
Shamay et al., 2005 (with added post-weaning protein)	2,162
Rincker et al., 2006 (proj. 305@ 150 DIM)	1,100
Drackley et al., 2007	1,841
Morrison et al., 2009	0
Moallem et al., 2010 (with added post-weaning protein)	1,613

Finally the data of Drackley et al. (2007) again demonstrates a positive response of early life nutrition on first lactation milk yield. In this study calves were fed either a conventional milk replacer (22:20; i.e. 22% protein, 20% fat) at 1.25% of the body weight (BW) or a 28:20 milk replacer fed at 2% of the BW for week one of treatment and then 2.5% of the BW from week 2 to 5 and then systematically weaned by dropping the milk replacer intake to 1.25% of the BW for 6 days and then no milk replacer. All calves were weaned by 7 weeks of age and after weaning all calves were managed as a single group and bred according to observed heats. The heifers calved between 24 and 26 months of age with no significant difference among treatments. Calving BW were also not different and averaged 1,278 lb. Milk yield on average was 1,841 pounds greater for calves fed the higher level of milk replacer prior to weaning.

The Cornell University Dairy Herd started feeding for greater pre-weaning BW gains many years ago and we have over 1,200 weaning weights and 3+ lactations with which to make evaluations outside of our ongoing study. What makes our approach to this unique is the application of a Test Day Model (TDM) (Everett, R. W., and F. Schmitz. 1994; Van Amburgh et al., 1997) for the analyses of the data. This approach allows us to statistically control for factors not associated with the variables of interest and is the same approach that has been used to conduct sire summaries and daughter evaluations and develop heritabilities for genetic traits. Thus, the outcome is mathematically more robust and allows us to look within a herd over time with less bias and to look at herd responses independent of formal treatments. The resulting residuals are standardized which makes them additive over the life of the animal and they can be calculated for individual test days or over the lactation. The power of this type of analyses is much more significant compared to comparing daily milk or even ME305 milk and helps us partition out variance not associated with the variables of interest.

We analyzed the lactation data of the 1,244 heifers with completed lactations using the TDM approach and statistically analyzed several factors related to early life performance and the TDM milk yield residuals (Soberon et al. submitted). The factors analyzed were birth weight, weaning weight, height at weaning, BW at 4 weeks of age and several other related and farm measurable factors. From a management perspective the most interesting observation was the relationship among two factors, growth rate prior to weaning and intake over maintenance and first lactation milk yield. In these analyses, the strongest relationship associated with first lactation milk production was growth rate prior to weaning and the findings are consistent with the data presented in Table 4. In our data set, for every 1 pound of average daily gain (ADG) prior to weaning (or at least 42 to 56 days of age), the heifers produced approximately 937 pounds more milk ($P < 0.01$). The range in pre-weaning growth rates among the 1,244 animals were 0.52 to 2.76 pounds per day and the range was actually quite puzzling to us. Our feeding program at the research farm is straightforward: 1.5% BW dry matter from day 2 to 7 and then 2% of BW dry matter from day 8 to 42 of a 28:15 or 28:20 milk replacer mixed at 15% solids. Free choice water is offered year around and starter is offered from day 8 onward. At that feeding rate, we are offering twice the industry standard amount and had assumed it was enough for overcoming the maintenance requirement and provide adequate nutrients for growth, even in the winter. However, when we analyzed the TDM residuals by temperature at birth, a very significant observation was made (Figure 1.

Figure 1. Test Day Model residuals in pounds of milk, averaged by temperature at time of birth with mean temperature in Fahrenheit. ($P < 0.001$)



This data very much suggests that although we are meeting the maintenance requirements of the calves from a strict requirement calculation, we are not providing enough nutrients above maintenance to optimize first lactation milk production. We need to remember that the thermoneutral zone for calves is 68° to 82° F and that when the temperature drops below that level, intake energy will be used to generate heat instead of growth. In addition, when we analyzed the data by lactation, the response increased as the animals matured (Table 5).

Table 5. Predicted differences by TDM residual milk (lb) for 1st, 2nd, and 3rd lactation as well as cumulative milk from 1st through 3rd lactation as a function of pre-weaning average daily gain and energy intake over predicted maintenance for the Cornell herd.

Lactation	n	Predicted difference in milk per lb of pre-weaning ADG	P value	Predicted difference in milk (lb) for each additional Mcal intake energy above maintenance	P value
1st	1244	850	< 0.01	519	< 0.01
2nd	826	888	< 0.01	239	0.26
3rd	450	48	0.91	775	< 0.01
1st - 3nd	450	2,280	0.01	1,991	< 0.01

This data demonstrates there are metabolic programming events being affected in early life that have a lifetime impact on productivity. When we evaluated the 450 animals that had completed a third lactation, we found a lifetime milk effect of pre-weaning average daily gain of over 6,000 lb of milk depending on pre-weaning growth rates. Further, 22% of the variation in first lactation milk production could be explained by growth rate prior to weaning. This suggests that colostrum status and nutrient intake and or pre-weaning growth rate have a greater effect on lifetime milk yield and account for more variation and progress in milk yield associated with the management of the calf than genetic selection. Generally, milk yield will increase 150 to 300 lbs per lactation due to selection whereas the effect of management is three to five times that of genetic selection.

An analysis of all the lactation data and the pre-weaning growth rates, when controlled for study, suggest that to achieve these milk yield responses from early life nutrition, calves must double their birth weight or grow at a rate that would allow them to double their birth weight by weaning (56 days). This further suggests that milk or milk replacer intake must be greater than traditional programs for the first 3 to 4 weeks of life in order to achieve this response.

What changes in the animal are allowing for these differences? There is no one answer to that question but investigations are looking for several factors. Although mammary development as previously measured is probably not the appropriate factor (Meyer et al., 2006a, 2006b), it is intriguing to look at very specific cells within the mammary gland. There are a couple sets of data that demonstrate increased mammary cell growth based on early life nutrient intake. Brown et al. (2005) observed a 32 to 47% increase in mammary DNA content of calves fed approximately 2 versus 1 pound of milk replacer powder per day through weaning. Just like the milk production increases discussed earlier, this mammary effect only occurred prior to weaning. In fact, this increase in mammary development was not observed once the calves were weaned, indicating the calf is more sensitive to level of nutrition prior to weaning and that the enhancement mammary development cannot be “recovered” once we wean the animal.

Meyer et al. (2006a) observed a similar effect in mammary cell proliferation in calves fed in a similar manner. The calves on their study demonstrated a 40% increase in mammary cell proliferation when allowed to consume at least twice as much milk replacer as the control group before weaning (Meyer et al., 2006a). Sejrsen et al (2000) observed no negative effect on mammary development in calves allowed to consume close to ad libitum intakes. A more specific attempt to look at stem cell proliferation did not find increased stem cells in calves fed higher levels of nutrient intake (Daniels et al., 2008) and it was hypothesized that the stem cell proliferation might lead to greater secretory cells once the animal becomes pregnant.

ECONOMICS

An in depth economic analyses of a program designed to double the birth weight and decrease age at first calving by almost 3 months was conducted by Dr. Mike Overton with input from Dr. Bob Corbett (Overton, 2010). In his analyses he utilized both research and herd data to characterize the costs and potential income associated with feeding and managing calves in a manner to promote a milk yield response. In his analysis, the first lactation profit was $190 per heifer without accounting for the increase in inventory and what that means to changes in either voluntary culling or heifer sales. The change in profitability was due to the average 1,700 lb milk response observed from the studies described in Table 4 and was adjusted for net present value of the investment today relative to the income two years from now.

We conducted our own analysis of the response using calf and heifer performance data from a herd used in a heifer cost benchmarking study from New York (Table 6). There are many terms for the difference in management of the calves – in this analyses we will call it intensified but it really represents more biologically normal growth. Actual health data, feed costs and total costs of rearing were included in the estimation. Age at first calving was a function of getting heifers pregnant at 55% of the mature body weight and then calving at a minimum of 82% in both systems. In our analyses, AFC was reduced by 2.3 months, but the costs associated with achieving the same body weight post calving were nearly identical due to the higher costs of feeds and the amount of feed consumed to achieve the earlier AFC.

While the cost per heifer completing the system did not change, there are several other areas where there is economic value associated with the decreased calving age and the decrease in non-performance expense. If start the same number of heifer calves each month, there will be on average 2 more animals completing the system each year. There is also a decrease in the total number of animals in the replacement program, dropping 8%. This could allow the dairy to grow larger with the same replacement system, or allow the dairy to investment in a replacement program that was 8% smaller than before. The third area to impact profitability is the increased performance of the heifer in the dairy herd.

Table 6. Cost assessment of conventional versus intensified calf and heifer programs

	Conventional	Intensified
Pre-weaning cost per pound gain, $	2.73	2.91
Total pre-weaning gain, lb	64	102
Age at pregnancy, mo.	15.4	12.2
Age at first calving, mo	24.5	22.2
Overall average daily gain from birth, lb	1.70	1.89
Body weight at calving, lb	1,350	1,350
Percent non-completion rate, % entering replacement program	10.2	7.5
Total cost per heifer, $	1,738	1,740
Total investment per heifer, $	1,887	1,890

Using a model that treats the replacement program as a separate enterprise within the dairy, we looked at the combined changes for this herd, decreasing the calving age to 22.2 months, decreasing the non-performance rate to 7.5%, and fully transferring the increased value of production in the lactating herd. The non-completion rate was reduced due to a reduction in death loss with greater nutrient intake prior to weaning with no changes post-weaning indicating there will be more heifers available to enter lactation. The base replacement enterprise was generating a return of 0.87% on assets invested in the replacement program. With all the changes, the return increased to 7.2%.

Table 7. Replacement enterprise impact for selected management changes for a 250 cow herd. These values represent the differences in expenses associated with the heifer rearing enterprise associated with the calf raising program.

	Base	Lower Calving Age	Lower Non-Completion Rate	Combined Changes
Heifers to cows ratio, %	76	68	74	69
Total rearing costs, $	1,736	1,739	1,701	1,724
Income per animal, $	1,900	1,900	1,900	2,104
Completing system total investment, $	223,142	202,348	217,508	211,692
% Return on Capital	0.87%	0.53%	1.75%	7.27%

The profitability increase is due to the potential decrease in inventory due to calving approximately 3 months earlier and the milk yield increase due to improved nutrition and management from birth. The management decisions associated with the inventory change due to AFC are difficult to generalize among all herds and it is really a one-time adjustment to the cost of production. However, given the potential change in milk yield over the life-time of the animal, the change in calf management in a program that maintains the targets throughout the growing phase is worth approximately $211, assuming a discount of 7% per year over the three year period, a $15 milk price, an income over feed costs of $10.50. This value is similar to the profit calculation of Mike

Overton and an outcome of the average milk response we are using to make the estimation along with the individual assumptions about costs of management.

SUMMARY

Early life events appear to have long-term effects on the performance of the calf. Our management approaches and systems need to recognize these effects and capitalize on them. We have much to learn about the consistency of the response and the mechanisms that are being affected. Given the amount of variation accounted for in first and subsequent lactation milk yield, there is opportunity to enhance the response once we know and understand those factors. The bottom line is there is a positive economic outcome to improving the management of our calf and heifer programs starting at birth.

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