Michigan State University
Michigan Alliance for Animal Agriculture

Improving Feed Efficiency for Financial and Environmental Sustainability

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CDCB Council on Dairy Cattle Breeding

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The basics of feed efficiency

Feed Available → Total Feed Gross Energy Consumed → Feed Net Energy → Energy captured as milk or body tissue

Feed Available → Feed wasted

Total Feed Gross Energy Consumed → Energy lost as feces, gas, urine, and heat for metabolizing feed

Digestibility
N utilization
Methane output
Heat increment
Residual feed intake

Feed Net Energy → Energy lost as heat for maintenance

Milk / BW
Partitioning

→**Increase net farm income and keep dairy foods cost competitive**

→**Improve environmental stewardship and reduce negative impacts/liter of milk**

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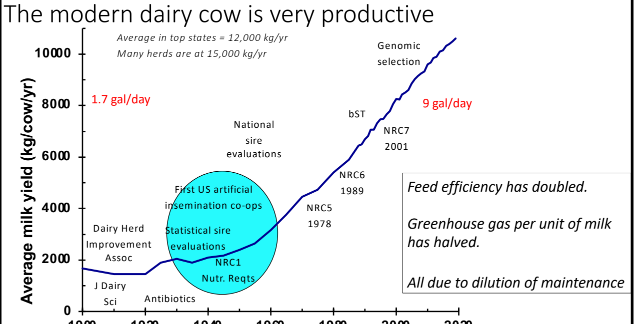
The modern dairy cow is very productive



Feed efficiency has doubled.

Greenhouse gas per unit of milk has halved.

All due to dilution of maintenance

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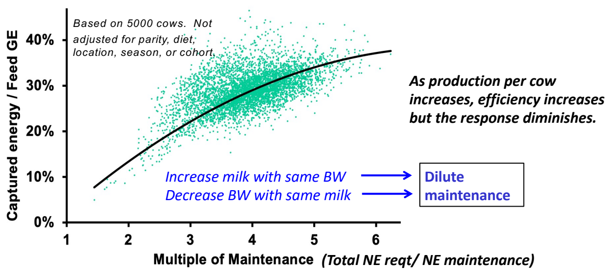
Increased productivity decreases feed used for maintenance



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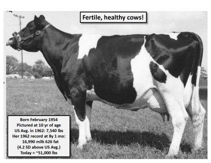
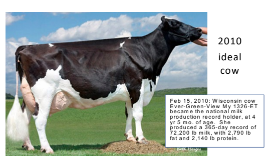
Breeding and feed efficiency

Goal: select for cows that give more milk per unit feed

- that produce more milk per unit body weight
- that need less feed than expected

1950s ideal cow





2010 ideal cow

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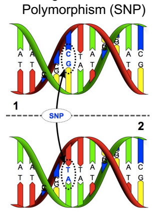
Genomic Selection

2 sets of 30 chromosomes, with 3 billion base pairs per set

Single Nucleotide Polymorphism (SNP)



Traditional breeding values are based on daughter performance. Genomics enables us to select for new traits and make decisions earlier on old ones.

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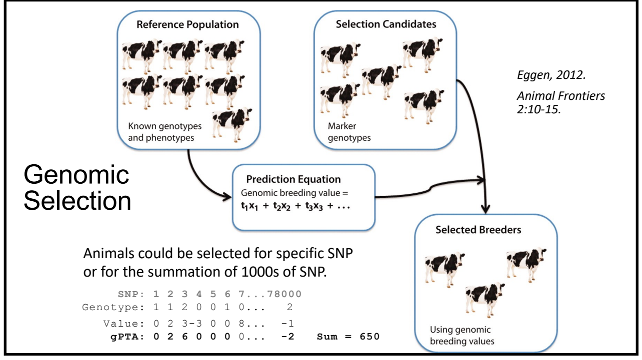

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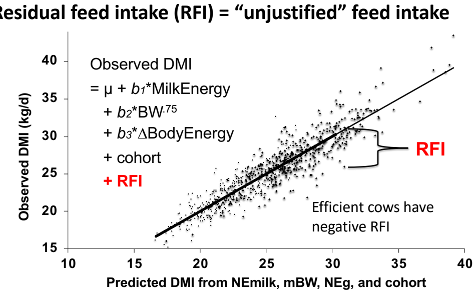
Residual feed intake (RFI) = "unjustified" feed intake



The heritability of RFI is 0.17, based on 4900 Holsteins from North America and Europe. (Tempelman et al., 2015)

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Genetic (upper right)and non-genetic (lower left) correlations and heritabilities (diagonal) for efficiency traits on 5700 Holsteins. Lu et al., unpublished.

	MilkE	MBW	DMI	Gross Eff.	IOFC
MilkE	0.37 ±0.03	0.06 ±0.06	0.66 ±0.04	0.66 ± 0.08	0.97 ±0.01
MBW	0.22 ±0.04	0.51 ±0.03	0.45 ±0.05	-0.28 ±0.06	0.02 ±0.07
DMI	0.56 ±0.02	0.37 ±0.03	0.38 ±0.03	-0.11 ±0.04	0.54 ±0.06
Gross Eff.	0.39 ±0.02	-0.03 ±0.01	-0.19 ±0.02	0.13 ±0.00	0.70 ±0.05
IOFC	0.85 ±0.01	0.17 ±0.04	0.34 ±0.03	0.77 ±0.01	

Selection against body size will enhance feed efficiency but not milk income per cow. Selection for milk increases both.

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Summary for body size and efficiency

Liu et al., 2015. Body weight.

- For 5700 Holsteins, body weight was not genetically correlated with milk energy per day. The genetic correlation of body weight with gross feed efficiency was -0.3.

Manzanilla-Pech et al., 2015. Stature.

- For 1900 US Holsteins, stature was not genetically correlated with milk energy/day. The genetic correlation of stature with gross feed efficiency was -0.7 and with residual feed intake was +0.4.

- ➢ **Selecting for bigger, taller cows does not increase milk.**
- ➢ **Selecting for bigger, taller cows decreases feed efficiency.**

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Maintenance requirement has increased

- NRC 2001: 0.08 x Metabolic BW
- Birnie et al., 2000: 0.084 to 0.113 x MBW
  depending on BCS
- Moraes et al, 2015: 0.086 to 0.115 x MBW
  depending on decade
- Tempelman et al., 2015: 0.11 to 0.17 x MBW
  depending on research farm
- NRC 2021: 0.10 x Metabolic BW

A higher coefficient for the maintenance requirement means cows needs to make more milk relative to BW to dilute maintenance out.

However, the more we select for higher production, the more we might be driving up the maintenance coefficient.

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Body Weight Composite (BWC) and efficiency

BWC = .23 x Stature + .72 x Strength + .08 x Body Depth + .17 x Rump Width - .47 x Dairy Form

Heritability is 40%. A 1-unit increase in BWC is ~35 lb mature BW. R = -0.8 for Dairy Form w BCS

Genetic correlations with other traits

Milk yield	Fat yield	Protein yield	Udder traits	Feet/ legs	Somatic cells	Heath index	Prod. life	Livability	Calving ability	Dtr preg rate	Concptn rates
−0.12	−0.05	−0.09	0.27	0.38	−0.10	−0.26	−0.10	−0.14	−0.07	-0.05	-0.01

Van Raden et al, 2018. USDA AIP report.

So if you breed for larger and taller cows, you can expect daughters that:

- will be bigger and taller and score higher at functional type traits
- will not produce more milk and will likely produce less milk and milk components
- may have shorter productive lives and die before they are sold
- may have lower SCS but will have poorer health and greater overall health costs
- will not differ in fertility and may have more calving problems
- will be less profitable because correlation with NM$2018 is -0.20

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Conclusions of our data so far

- Stature and body weight are negatively correlated with Gross Feed Efficiency at r = -0.7 and -0.3.
- Maintenance requirement per BW is at least 25% higher than we thought.
- Residual feed intake (RFI) is moderately heritable at ~0.17.
- 61,000 SNP markers accounted for 14% of the variance in RFI. Top ten SNP accounted for 7% of the variance.
- Residual feed intake is a trait worthy of inclusion in net merit, but low REL for young animals will limit progress.

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$Feed Saved: a new trait to include in the Net Merit Index

- **Feed is saved when cows are smaller but continue to produce as much milk--they produce more milk per unit of body weight**
- **Feed is saved when cows have lower Residual Feed Intake (RFI)--they eat less than expected based on their milk production, body weight, and body weight change.**
- Feed Saved PTAs of the top 100 bulls for Net Merit range from -183 to +395 pounds per lactation.
- Economic value of Feed Saved is quite large, and the relative economic weight proposed for this new trait in Net Merit is 21% (this can be broken down as -9% for BWC and -12% for RFI).
- Net Merit will continue to focus on increasing milk protein and fat yields.
- We expect the addition of Feed Saved to provide an extra $8 million per year in net profit to U.S. dairy farmers, and these gains will accumulate over time.

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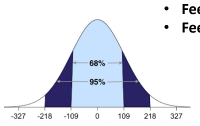
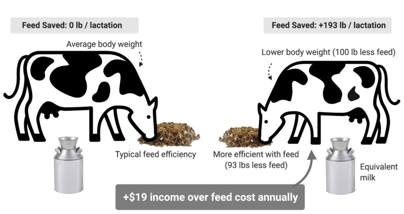
$Feed Saved: a new trait to include in the Net Merit Index

- **Feed is saved when cows are smaller but produce as much milk**
- **Feed is saved when cows have lower Residual Feed Intake (RFI)**



Daughters of top bulls will consume 200 lb less feed (1%) per year but produce as much milk.



Only a 1% decrease in feed use per year, but it's cumulative!

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Net Merit (NM$) – Selection Index

	1971	2010	2014	2018	2021?
Milk Yield	52	0	-1	-1	0
Fat Yield	48	19	22	27	22
Protein Yield		16	20	17	17
Productive Life		22	19	12	15
Udder Composite		7	8	7	3
Feet/legs Composite		4	3	3	1
Daughter Pregnancy Rate		11	7	7	5
Cow+Heifer Conception Rate		-	3	3	2
Calving Ability		5	5	5	3
Somatic Cell Score		-10	-7	-4	-3
Health trait subindex				2	2
Livability				7	5
Early first calving					1
Body Weight Composite		-6	-5	-5	-9
Residual Feed Intake					-12

AGIL report, 2021

Feed Saved

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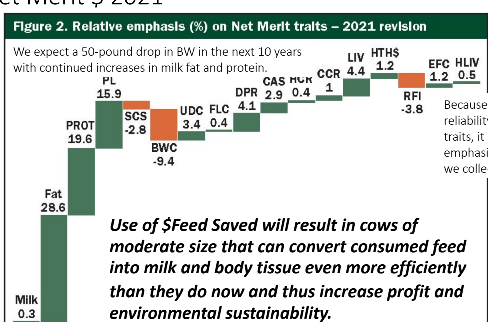
Net Merit $ 2021



Because RFI has a lower reliability than most other traits, it has less relative emphasis. This will increase as we collect more data.

Use of $Feed Saved will result in cows of moderate size that can convert consumed feed into milk and body tissue even more efficiently than they do now and thus increase profit and environmental sustainability.

From Durr, 2021, Hoards Dairyman

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Current project

Improving dairy feed efficiency, sustainability, and profitability by impacting breeding and culling decisions.

- ***Keep our reference population up to date with feed intakes of more cows and improve reliabilities of breeding values for RFI.***
- ***Determine if sensors and milk spectral data can be used to more accurately estimate intake of individual cows in group-fed systems.***
- ***Determine the relationship of feed efficiency and methane emissions.***
- ***Identify mechanisms underlying differences in efficiency among cows.***

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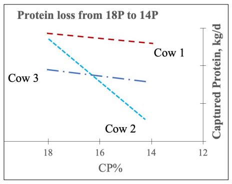
Resilience to low protein

J. Dairy Sci. 103:11401–11412
https://doi.org/10.3168/jds.2020-18143

Low dietary protein resilience is an indicator of the relative protein efficiency of individual dairy cows

E. Liu and M. J. VandeHaar*
Department of Animal Science, Michigan State University, East Lansing 48824



Cows that are resilient to low dietary protein produce more milk protein than expected based on stage of lactation, body weight, body weight change, and cohorts when fed a diet marginally deficient in protein

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Feeding and feed efficiency

Goal: stimulate milk synthesis and supply the nutrients for it

When making decisions for diets and feed management:
- Once maintenance is supplied, every extra Mcal of feed will likely result in more milk. In general, 1 more pound of feed means 2 more pounds of milk.
- Maximum feed intake generally results in maximum milk.
- Maximum milk usually means greater efficiency.
- More milk and efficiency usually translates to greater profitability, unless feeds are expensive relative to milk price.
- More milk and efficiency usually decreases wastes per unit of milk produced.

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Feeding: What efficiency metric to use

	Fiber	Starch	Protein	Fat
GE	4 kcal/g	4 kcal/g	6 kcal/g	9 kcal/g
NE	1-2	~2	~2	4-8

Nutrients interact to alter the energy available for making milk and thus efficiency.

Milk/feed
- Favors fats
- Favors starch
- Disfavors fiber

Milk E / Feed GE or Captured E / Feed GE
- Favors starch
- Disfavors fiber
- Disfavors protein

Milk E / Feed NE
- Hard to measure

Income over feed cost

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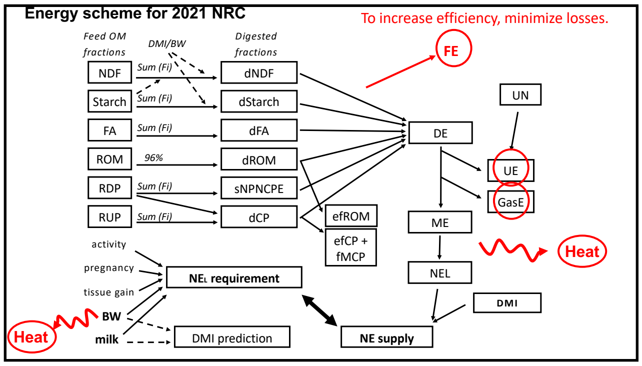

Energy scheme for 2021 NRC
To increase efficiency, minimize losses.
Feed OM fractions
DMI/BW
Digested fractions
NDF
Starch
FA
ROM
RDP
RUP
Sum (Fi)
96%
dNDF
dStarch
dFA
dROM
sNPNCPE
dCP
efROM
efCP + fMCP
FE
DE
UN
UE
GasE
ME
NEL
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BW
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NEL requirement
DMI prediction
NE supply
DMI
Heat

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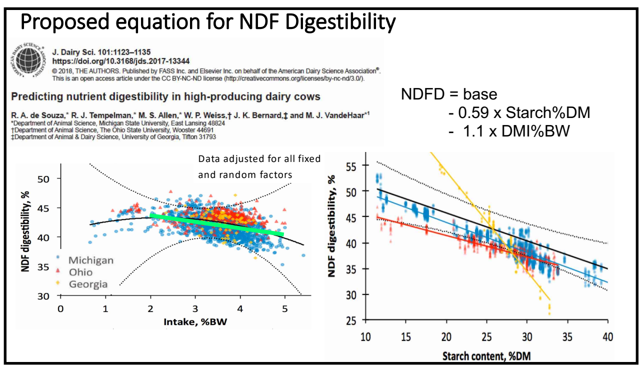

Proposed equation for NDF Digestibility
J. Dairy Sci. 101:1123–1135
https://doi.org/10.3168/jds.2017-13344
Predicting nutrient digestibility in high-producing dairy cows
R. A. de Souza, R. J. Tempelman, M. S. Allen, W. P. Weiss, J. K. Bernard, and M. J. VandeHaar
NDFD = base
- 0.59 x Starch%DM
- 1.1 x DMI%BW
Data adjusted for all fixed and random factors
NDF digestibility, %
Michigan
Ohio
Georgia
Intake, %BW
Starch content, %DM

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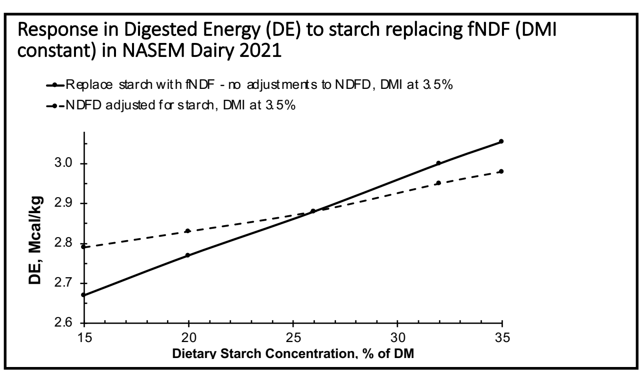

Response in Digested Energy (DE) to starch replacing fNDF (DMI constant) in NASEM Dairy 2021
Replace starch with fNDF - no adjustments to NDFD, DMI at 3.5%
NDFD adjusted for starch, DMI at 3.5%
DE, Mcal/kg
Dietary Starch Concentration, % of DM

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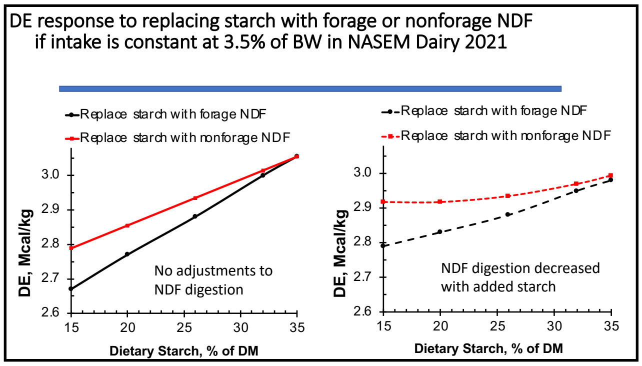

DE response to replacing starch with forage or nonforage NDF
if intake is constant at 3.5% of BW in NASEM Dairy 2021
Replace starch with forage NDF
Replace starch with nonforage NDF
DE, Mcal/kg
No adjustments to NDF digestion
Dietary Starch, % of DM
Replace starch with forage NDF
Replace starch with nonforage NDF
DE, Mcal/kg
NDF digestion decreased with added starch
Dietary Starch, % of DM

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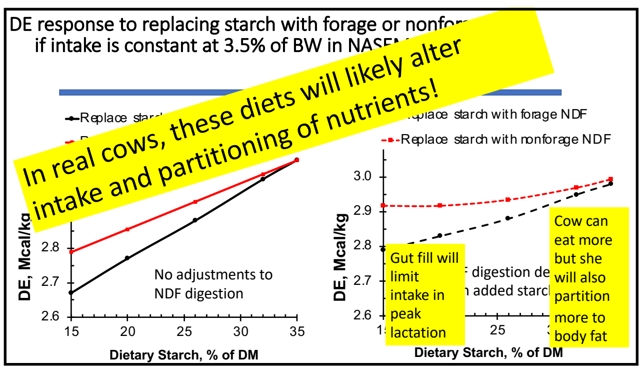

In real cows, these diets will likely alter intake and partitioning of nutrients!
Replace starch with forage NDF
Replace starch with nonforage NDF
DE, Mcal/kg
No adjustments to NDF digestion
Dietary Starch, % of DM
DE, Mcal/kg
Gut fill will limit intake in peak lactation
Cow can eat more but she will also partition more to body fat
Dietary Starch, % of DM

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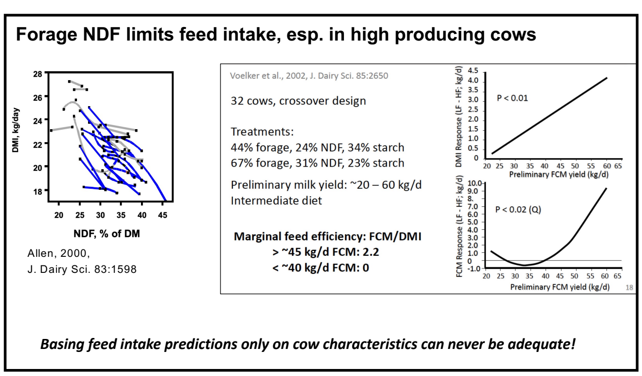

Forage NDF limits feed intake, esp. in high producing cows
DMI, kg/day
NDF, % of DM
Allen, 2000,
J. Dairy Sci. 83:1598
Voelker et al., 2002, J. Dairy Sci. 85:2650
32 cows, crossover design
Treatments:
44% forage, 24% NDF, 34% starch
67% forage, 31% NDF, 23% starch
Preliminary milk yield: ~20 – 60 kg/d
Intermediate diet
Marginal feed efficiency: FCM/DMI
> ~45 kg/d FCM: 2.2
< ~40 kg/d FCM: 0
DMI Response (LF - HF; kg/d)
P < 0.01
Preliminary FCM yield (kg/d)
FCM Response (LF - HF; kg/d)
P < 0.02 (Q)
Preliminary FCM yield (kg/d)
Basing feed intake predictions only on cow characteristics can never be adequate!

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J. Dairy Sci. 102:7961–7969
https://doi.org/10.3168/jds.2018-16166

Equation to predict feed intake response by lactating cows to factors related to the filling effect of rations

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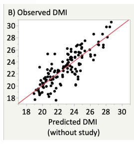
[1]Department of Animal Science, Michigan State University, East Lansing 48824
[2]Department of Animal Science, University of São Paulo, Pirassununga, SP, 13635-900 Brazil

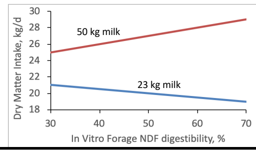
Table 4. Fit statistics for the proposed equation using all data and for the 5-fold cross validation

Fit statistic[1]	All data	Cross validation
Observed mean, kg/d	23.0	22.5
Predicted mean, kg/d	23.0	22.3
Mean bias, kg/d	0.00	−0.26
RMSE, kg/d	1.55	1.69
RMSE, % of mean	6.71	7.53
CCC	0.827	0.768

[1]RMSE = root mean square error; CCC = concordance correlation coefficient.

DMI (kg/d)
= 12.0 + 0.225 × MY − 0.107 × FNDF
+ 8.17 × ADF/NDF + 0.0253 × FNDFD
− 0.328×(ADF/NDF−0.602)×(FNDFD−48.3)
+ 0.00390×(FNDFD−48.3)×(MY−33.1)





Feed factors will improve our DMI predictions, but it's complicated and we still have more to learn.

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Substitution of beet pulp for barley grain in late lactation

18 Holstein cows, last 2 months of lactation, 171±16 d pregnant

Barley grain:	24%	15%	6%	
Beet pulp:	0%	9%	17%	
<u>%starch</u>	<u>19</u>	<u>15</u>	<u>12</u>	<u>*P (lin)*</u>
DMI, kg/d	18	18	18	NS
Milk, kg/d	18	17	18	NS
Milk fat, kg/d	0.78	0.84	0.90	0.1
MilkE, Mcal/d	13.9	14.3	15.2	0.1
dBCS, units/per.	+0.13	-0.09	-0.12	0.01
dBFT, mm/per.	+2.5	-0.4	-1.6	<0.01
Insulin, ng/ml	0.93	0.75	0.72	0.05
pH	5.8	6.0	6.2	<0.01

Replacing starch with nonforageNDF increased milk energy output but decreased insulin and body gain.

Mahjoubi et al., 2009, AFST 153:60-66

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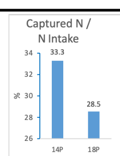
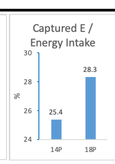
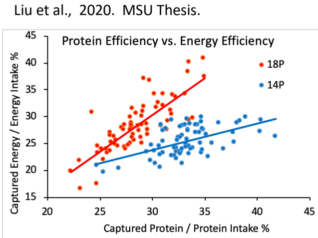
Relationship of protein and energy efficiency

170 Holstein cows in mid-lactation fed 18 or 14% CP diets in two 28-d treatment periods. Liu et al., 2020. MSU Thesis.







- Low protein can increase protein efficiency but will decrease energy efficiency if milk production decreases.
- Balancing protein sources and perfecting bypass AA blends will help optimize both protein and energy efficiency at the same time.
- Better methods for monitoring responses on farms are needed. They must include BW response.

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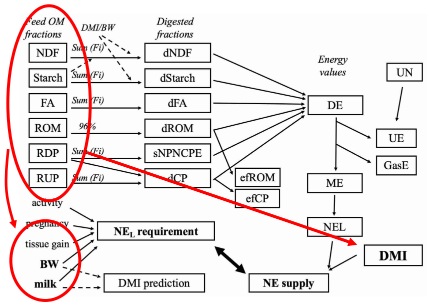
Feeding effects on efficiency



Intake and partitioning responses must be considered and monitored when balancing diets to maximize the energy available for milk and thus maximize efficiency.

No nutrition models do a good job of this.

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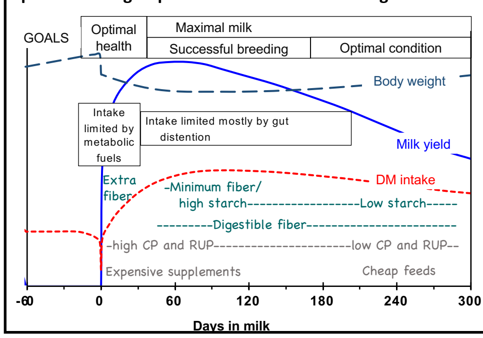
Optimal feeding requires more than one lactating diet



One diet cannot be optimal for all stages.

Feeding management of that optimal diet is also key.

- *Maximize intake*
- *Minimize sorting*

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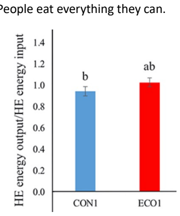
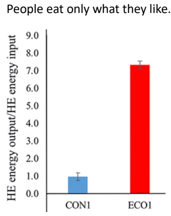
Cows give more "human-edible" nutrients than they eat

Question: what is "human-edible"?

Thrift scenario.
People eat everything they can.



Choice scenario.
People eat only what they like.



Takiya et al., 2019. Front. Sustain. Food Syst. 3:114.

HE recovery of lysine was 500 for choice scenario.

CON1 = Control diet: 31% by-products feeds.

ECO1 = Ecological-leftovers diet: 95% byproduct feeds.

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Take-home points

- We want cows that convert feed to milk efficiently and profitably.
- Effective breeding to increase feed efficency requires continuing to select for more milk components while also selecting against body size and residual feed intake in Net Merit.
- Effective feeding to increase feed efficiency requires consideration of nutrient interactions for digestion and metabolism and diet effects on the regulation of feed intake and nutrient partitioning. One diet cannot be optimal for all lactating cows. Computer models do not accurately predict intake and partitioning.
- Greater feed efficiency may not reduce methane much in North American cows. Feeding fat will help, but we need some new additives.
- Making milk is an efficient process and cows can convert poor quality foods into high quality food for humans. We need to make sure consumers hear that message.

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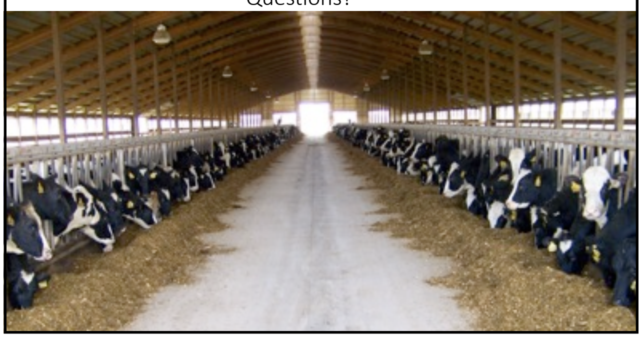
Questions?



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