Onset of heat stress and development of genomic predictions for heat tolerance in US Holsteins and Jerseys

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How dairy cattle experience heat

To maintain a constant body temperature, heat gained has to equal heat loss:

$$Heat\ loss = Heat\ Gain$$

$$Heat\ loss = Heat\ Produced + Environmental\ Heat$$

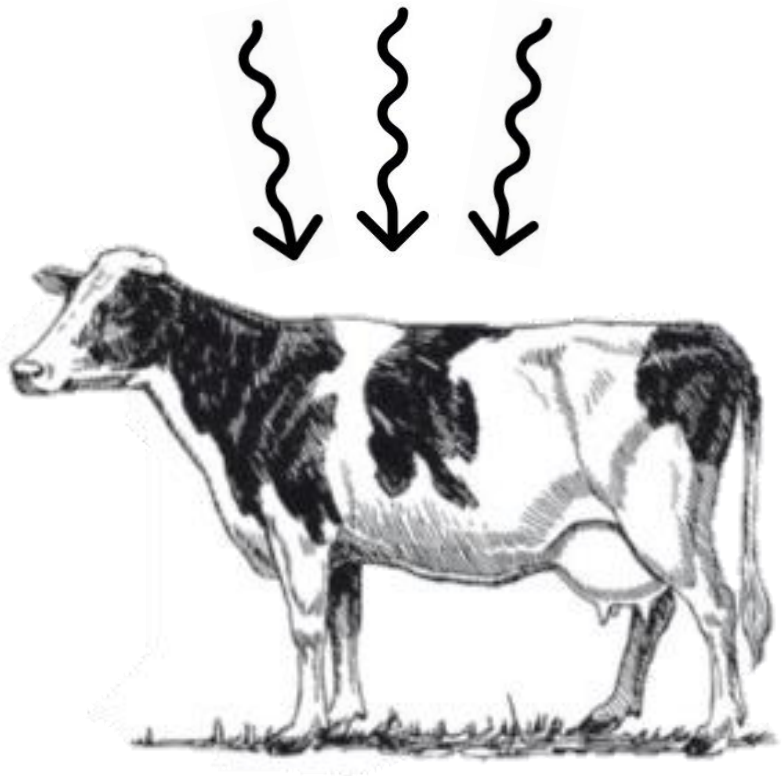
Heat stress occurs when heat gain *exceeds* heat loss:

$$Heat\ loss < Heat\ Gain$$

$$Heat\ loss < Heat\ Produced + Environmental\ Heat$$

Robertshaw (1985); Hansen (1994)

Excessive environmental heat



↑ water consumption

↓ feed intake (DMI)

↑ somatic cell count

↓ milk yield

↓ fertility

↓ rumen function

↓ immunity

↑ risk of mastitis/disease

Heat management strategies

Environmental:

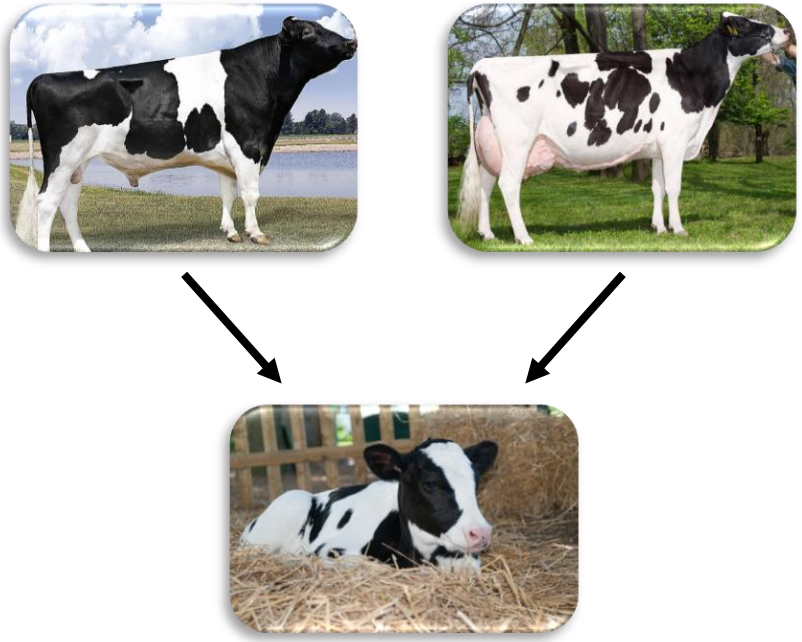
Sprinklers

Shade

Ventilation/fans

Feed/water schedule

Genetic:

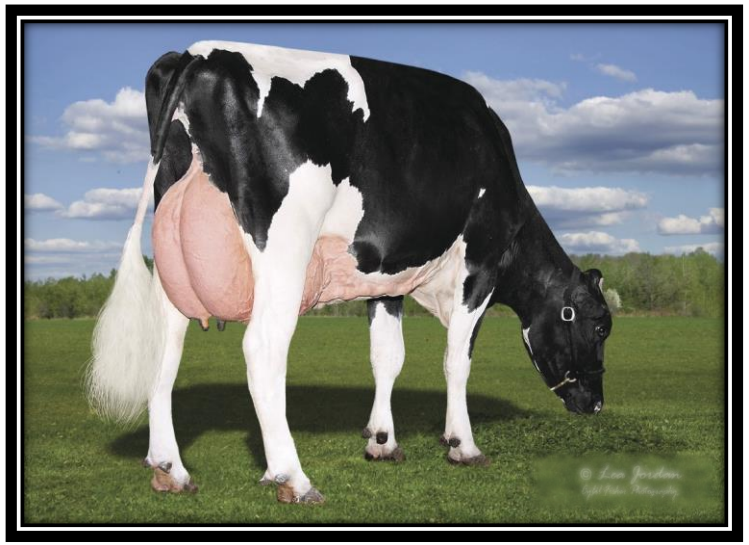


Breeding for heat tolerance

Goal of this research

To investigate the impact of heat stress on production traits in US Holstein and Jersey cattle

1. Determine heat threshold
2. Estimate genetic parameters
3. Calculate genomic predictions



Traits of interest: test-day yields

milk, fat, and protein yield (kg)

Data edits
for quality control

- Lactations 1 - 5
- ≥5 test-day rec. per lactation
- DIM between 5 and 305 days
- Outlying phenotypes removed (MAD)

Breed	No. TD records	No. Cows	No. Genotyped
Holstein	12.8 million	923,311	76,481
Jersey	2.1 million	153,714	46,046

Represent 331 herds in 27 US states

2015 - 2021

Temperature-humidity index (THI)

$$THI = (1.8 * T_{celsius} + 32) - [(0.55 - 0.0055 * RH) * (1.8 * T_{celsius} - 26.8)]$$

National Research Council (1971)

- Indicator of heat stress risk
  - Little to no heat stress
  - Moderate heat stress
  - High heat stress
  - Deadly heat stress

Temperature Humidity Index (THI) Relative Humidity %									
C	20	30	40	50	60	70	80	90	100
22	66	66	67	68	69	69	70	71	72
24	68	69	70	70	71	72	73	74	75
26	70	71	72	73	74	75	77	78	79
28	72	73	74	76	77	78	80	81	82
30	74	75	77	78	80	81	83	84	86
32	76	77	79	81	83	84	86	88	90
34	78	80	82	84	85	87	89	91	93
36	80	82	84	86	88	90	93	95	97
38	82	84	86	89	91	93	96	98	100
40	84	86	89	91	94	96	99	101	104

- Weather data obtained from airports closest to each herd *(mean distance 19 km)*
  - Iowa State University's Iowa Environmental Mesonet

- 5-day average THI was used for each herd-test-day

Heat threshold analysis: Repeatability model

$$y = HTD + (DIM * season) + lact + state + age + THI + \mathrm{a} + pe + e$$

FIXED EFFECTS

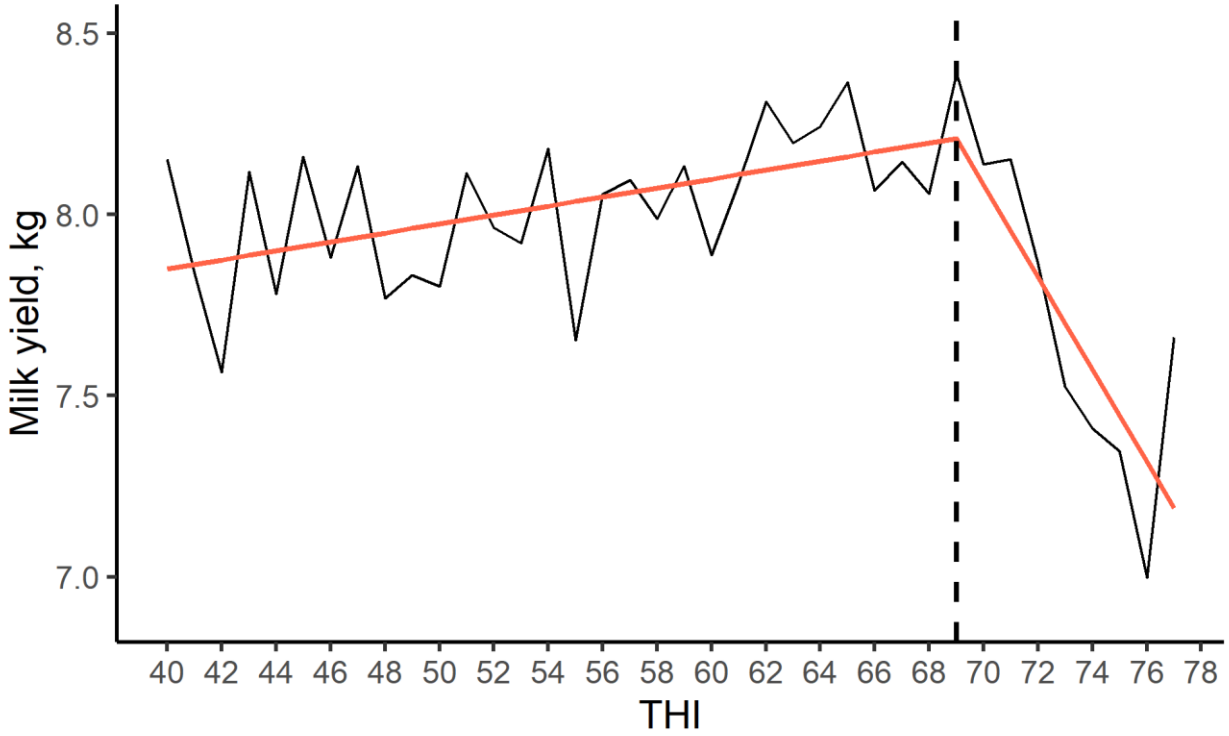
- y phenotype (3-trait model: milk, fat, and protein yield)
- HTD herd-test-day
- DIM days-in-milk
- $season$ calving season
- $lact$ lactation
- $state$ location in US
- age age at calving
- THI Temperature-humidity index of herd-test-day

RANDOM EFFECTS

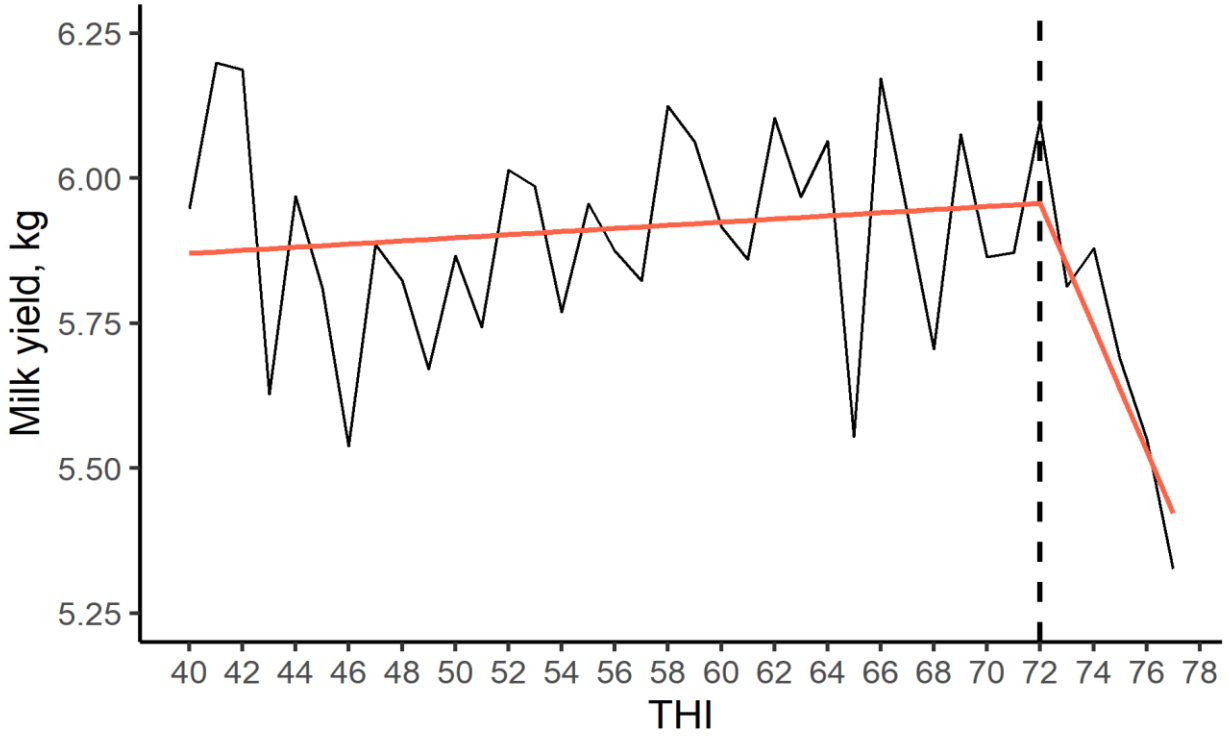
- a additive genetic component
- pe permanent environment component
- e residual

Heat threshold results

HOLSTEIN



JERSEY



Genomic Prediction: Reaction Norm

$$y = HTD + (DIM * season) + lact + state + age + \mathrm{a} + \alpha[f(THI)] + pe + \pi[f(THI)] + e$$

- y phenotype (milk, fat, and protein yield; kg)

FIXED EFFECTS

- HTD herd-test-day
- DIM days-in-milk
- $season$ calving season
- $lact$ lactation
- $state$ location in US
- age age at calving

RANDOM EFFECTS

- a additive genetic component ← General genetic merit of production
- $\boldsymbol{\alpha[f(THI)]}$ **additive heat tolerance genetic component** ← Heat tolerance genetic merit of production
- pe permanent environment component
- $\boldsymbol{\pi[f(THI)]}$ **permanent environment heat tolerance component**
- e residual

Genotype-by-environment interaction (GxE)

- Random effects were regressed on a function of THI

$$f(THI) = \begin{cases} 0 & \text{THI}_{\text{TD}} \leq \text{THI}_{\text{threshold}} \ (no\ heat\ stress) \\ (\text{THI}_{\text{TD}} - \text{THI}_{\text{threshold}}) & \text{THI}_{\text{TD}} > \text{THI}_{\text{threshold}} \ (heat\ stress) \end{cases}$$

In Holstein: $\text{THI}_{\text{threshold}} = 69$
In Jersey: $\text{THI}_{\text{threshold}} = 72$

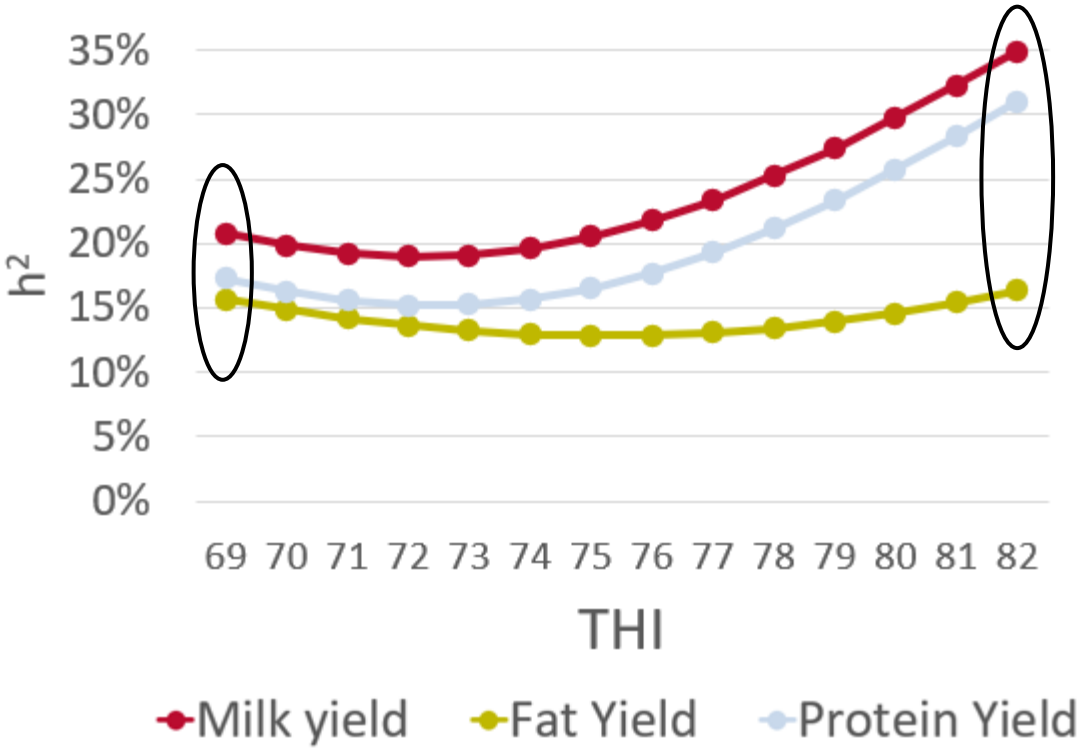
Heritability (h^2) and Correlation

- h^2 for general genetic merit ($no\ heat\ stress$)
- h^2 for genetic merit ($with\ heat\ stress$)
- Genetic correlation between general and heat tolerance additive effects

Heritability of production traits across heat stress

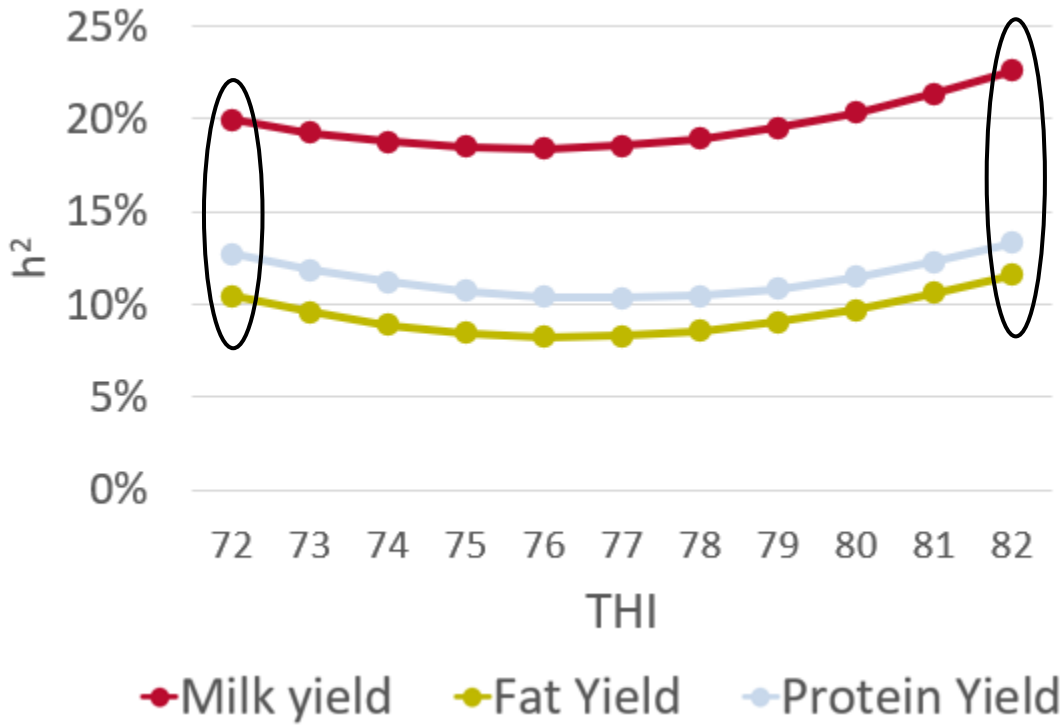
HOLSTEIN

Onset of heat stress for Holstein: 69



JERSEY

Onset of heat stress for Jersey: 72



Correlations

Relationship between general genetic merit and

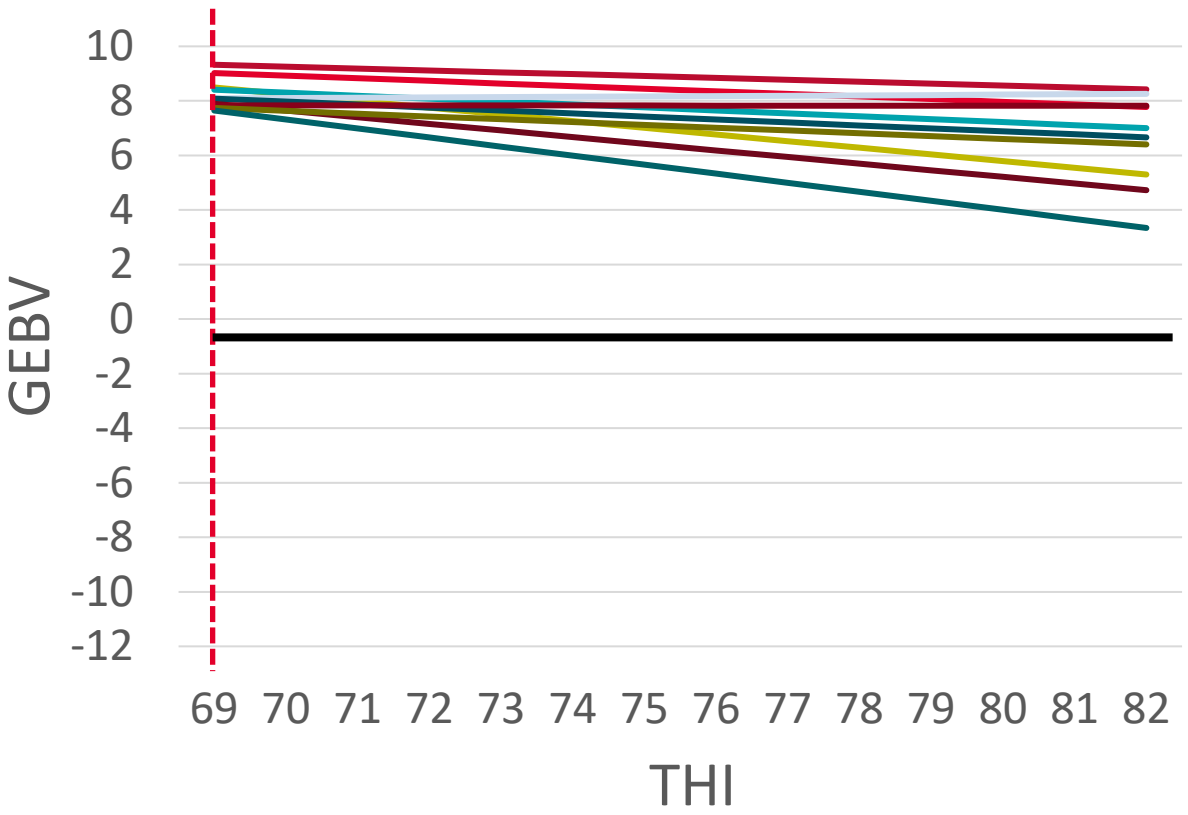
heat tolerance genetic merit of production

	Holstein	Jersey
Milk yield	-0.38	-0.37
Fat yield	-0.51	-0.49
Protein yield	-0.43	-0.52

- Negative correlations indicate opposing relationship, but they are moderate
  - Possibility some animals have a *relatively* high general *and* heat tolerance genetic merit

Holstein (milk)

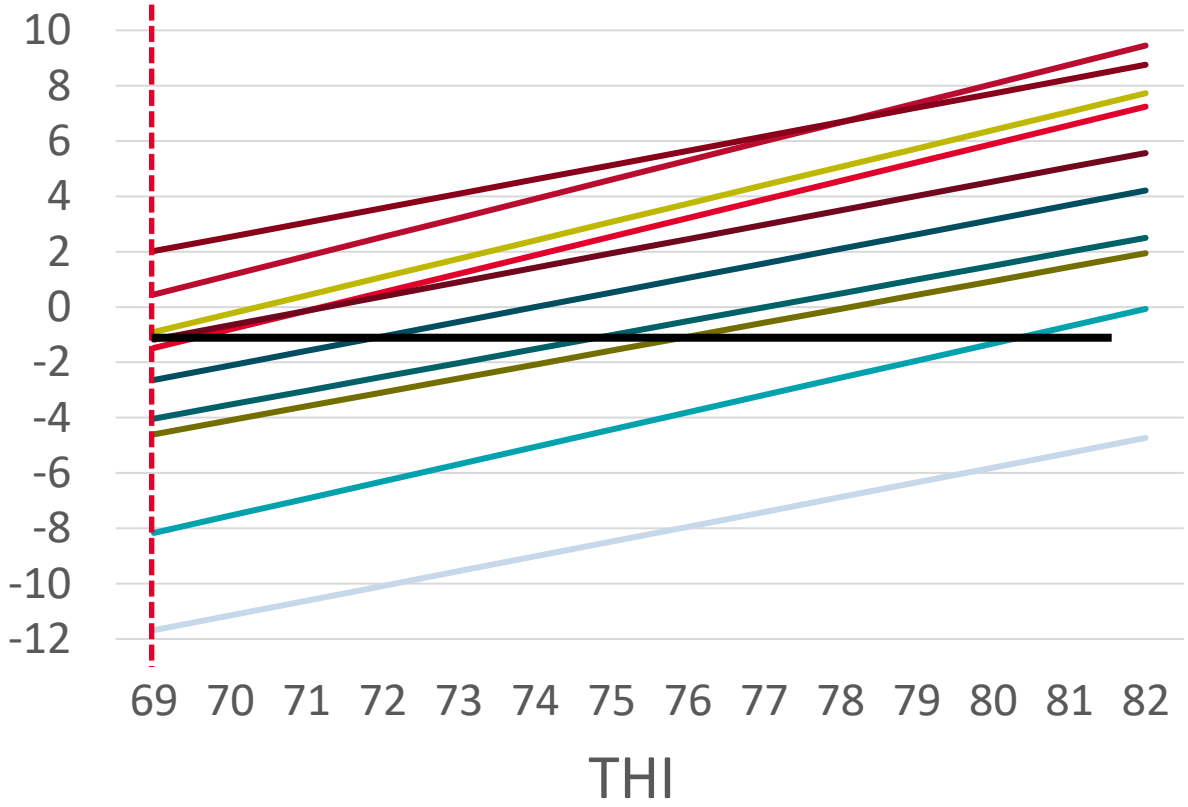
Top 10 animals for general genetic merit



High general genetic merit for milk

Avg. or below avg. decline in production due to heat stress

Top 10 animals for heat tolerance genetic merit



Avg. or below avg. general genetic merit for milk

Above avg. performance under heat stress

Conclusions

- Heat stress was determined to cause a decrease in production at
  - THI 69 for Holstein
  - THI 72 for Jersey
- Impact of heat stress on test-day yields depends on both:
  - ~10-30% genetics
  - ~70-90% environment/management

  } breed and trait dependent
- Moderate, negative correlation between general genetic merit and heat tolerance

  genetic merit of production
  - High producing cows are expected to have a lower heat tolerance

Conclusions continued

- h^2 ↑ under heat stress for Holstein milk and protein yield
  - Potential to improve heat tolerance through genetic selection
- The genetic component is not as clear for Jersey

1st and later lactations included as fixed effect

- Genetic selection could include both (i) general genetic merit of production and (ii) heat tolerance genetic merit of production
- *Ongoing research*: first and later lactations as separate evaluations

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