Genetic Correlation
Genotype by Environment Interaction

Lecture 13

Introduction to Breeding and Genetics

GENE 251/351

School of Environment and Rural Science (Genetics)

Overview

- Relationships between traits
- Indirect selection
- Genotype x environment interaction

Relationships between traits

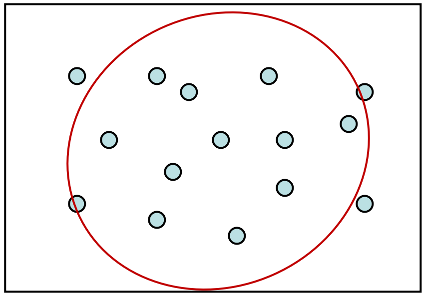
- Animals with higher growth rate tend to be fatter
- Animals with higher weaning weight tend to have higher birth weight
- Animals with lower body weight tend to have smaller litter sizes
- Sheep with finer fleeces cut less wool

Relationships between traits: why?

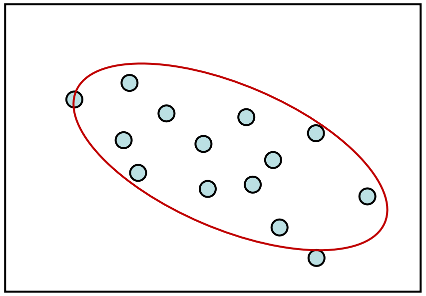
- Genetic:
  - Pleiotropy: Same gene influences two traits
  - Linkage: Genes for 2 traits are tightly linked, i.e. located close together on the same chromosome
- Environmental
  - Same random effects affecting both traits

What does the relationship look like?

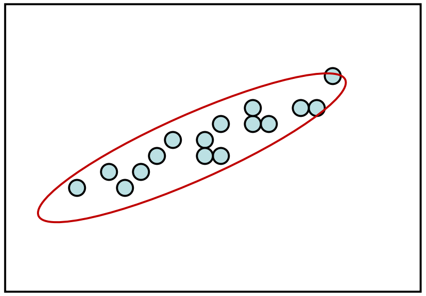
- Graph of trait y versus trait x
  - No association
  - Negative association
  - Positive association
  - See page 52 Simm



Correlation r~0.01



Correlation r~ -0.50



Correlation r~0.99

Describing the association between traits

- The direction and strength of the association between traits can be described by two related parameters
  - – the *regression coefficient* (b)
  - – the *correlation coefficient* (r)

Describing associations

- *Covariance*
  - *Sum of crossproducts*

$$Cov(X,Y) = \frac{\Sigma(X-\bar{X})(Y-\bar{Y})}{n-1}$$

Describing associations

– *Covariance*

$$Cov(X,Y) = \frac{\Sigma(X - \bar{X})(Y - \bar{Y})}{n-1}$$

– *Regression* - measures extent which changes in one trait are associated with changes in another, in units of measurement. *Used for prediction*

$$b_{Y,X} = \frac{Cov_{x,y}}{V_x}$$

Describing associations

- *Covariance*

$$Cov(X,Y) = \frac{\Sigma(X-\bar{X})(Y-\bar{Y})}{n-1}$$

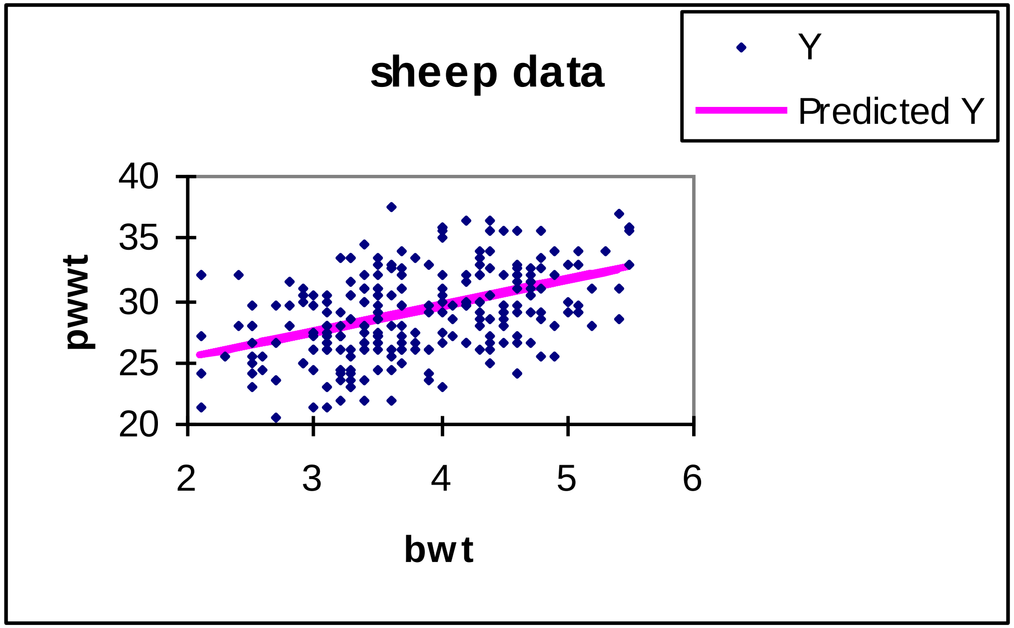
- *Regression* - measures extent which changes in one trait are associated with changes in another, in units of measurement. *Used for prediction*

$$b_{Y,X} = \frac{Cov_{x,y}}{V_x}$$

- *Correlation* - measures association between traits, but on scale -1 to 1, rather than units of measurement

$$r_{X,Y} = \frac{Cov_{x,y}}{\sigma_X \sigma_Y}$$

Regression:
Predicting a variable from another one

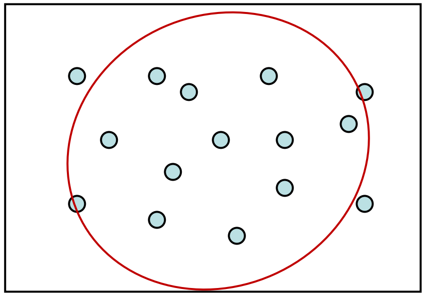


- Slope = $b_{pwwt,bwt}$=2.125

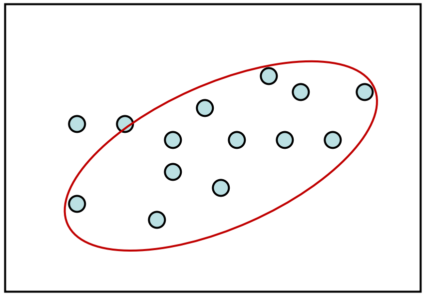
→1 kg change in birth weight (bwt) is expected to result in a 2.125 kg change in post-weaning weight (pwwt) on average

More on correlation

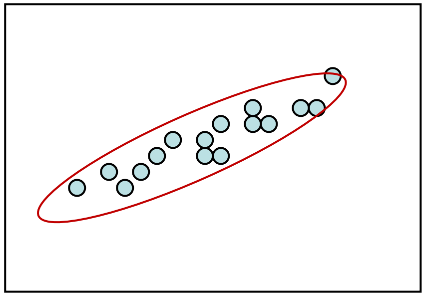
- Express relationship in SD units
  - e.g. r = -0.5 then animals +1 SD unit in one trait are expected to be -0.5 SD units on average in second trait
- Look at sign
  - Tells whether association is +ve, 0, or -ve
- Look at size
  - Tells how closely individual points are clustered around the line drawn through them
  - If correlation is +1 or -1 then all points are on line



Correlation r= ~0.01



Correlation r= ~ -0.50



Correlation r ~0.99

covariance, regression, correlation
example

$Y = [2, 4, 6, 8, 10]$ $V_Y = 10$ $\sigma_y = 3.16$

$X = [1, 2, 3, 4, 5]$ $V_X = 2.5$ $\sigma_x = 1.58$

Covariance: $\text{Cov}_{Y,X} = 5$

Regression $b = \text{Cov}_{Y,X} / V_X = 5/2.5 = 2$

2 units change in Y for every 1 unit change in X

Correlation $r = \text{Cov}_{Y,X}/(\sigma_X * \sigma_Y) = 5/(1.58 \times 3.16) = 1$

1 stddev change in Y for every 1 stddev change in X

Types of correlations

- Phenotypic correlations
  - measure association between observed performance
  - Cows that produce more milk tend to have lower fertility

- Genetic correlations
  - measure association between breeding values
  - Bulls that give daughter that produce more milk tend to have daughters with lower fertility

  - Due to pleiotropy or linkage (may be +ve or –ve)

Types of correlations

- Phenotypic correlations (r_P)
  - measure association between observed performance
- Genetic correlations (r_A)
  - measure association between breeding values
- Environmental correlations (r_E)
  - measure association between random environmental effects

- Recall Variances add up $V_P = V_A + V_E$
- Similarly Covariances add up $Cov_P = Cov_A + Cov_E$

But correlations do not add up! $r_p \neq r_A + r_E$

- Cov_A and Cov_E can differ
  - e.g. muscle depth and fertility may have no genetic covariance (and thus no genetic correlation),

    but can have a positive environmental covariance (and thus a positive environmental correlation)

une

Use of correlations

- Predict change in one trait when selecting on another (use genetic correlation)
- Construct selection indexes involving multiple traits
- Provide an additional information source in terms of predicting breeding values

What is indirect selection?

- Selecting on one trait (x) when interested in response in another trait (y)

- Examples
  - selecting on ultrasound muscle depth to improve carcas muscle area
  - selecting on fecal egg count to improve disease resistance
  - selecting on scrotal circumference to improve fecundity
  - selecting on CV of fibre diameter to improve staple strength

Why use indirect selection?

- If traits is difficult or expensive to measure
    - Feed intake
    - Carcase Traits

  Select on another correlated trait that is easier to measure

- If traits can only be measured late in life

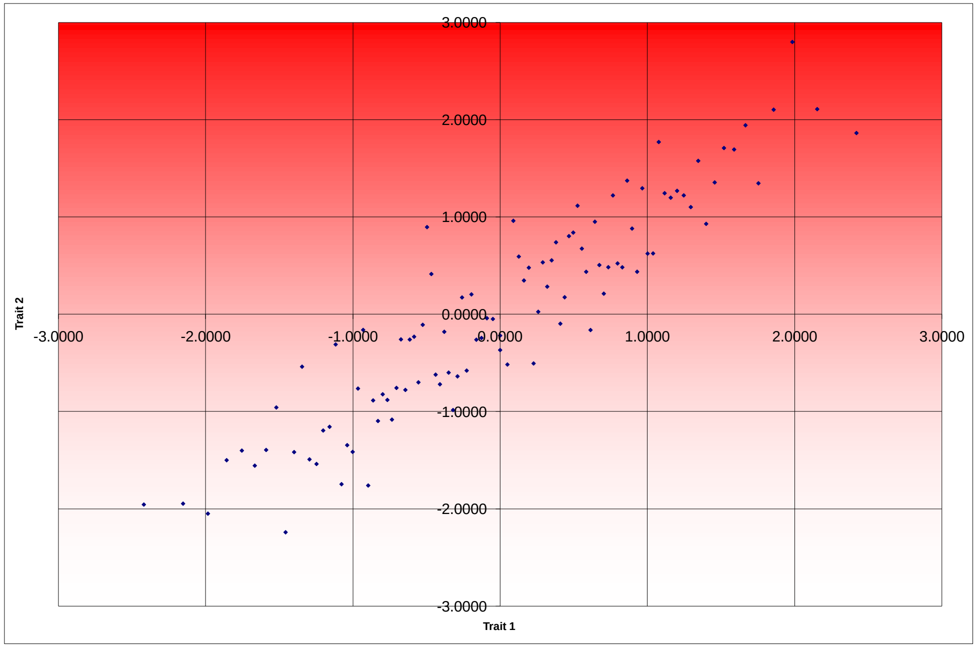
  Select on a correlated trait that can be measured earlier

- If traits have very low heritability

  Select on a (highly) correlated trait that is more heritable

Predicting the correlated response

Breeding value trait y



Breeding value trait x

We can predict breeding values for trait y from breeding values for trait x

$$\hat{A}_Y = b_A A_x$$

b = slope is regression of trait y on trait x

Predicting the correlated response

- Correlated response in trait y
  - from before $$\hat{A}_y = b_A A_x$$ *regression of BVs*
  - Similarly $$CR_y = b_A R_x$$ *regression of response*

Correlated response (CR_y) = response in trait y due to selection on trait x.

Given

$$R_x = i_x h_x^2 \sigma_{Px}$$

Response in trait x selected on

$$CR_y = b_A R_x$$

Correlated Response in trait y

from derivation

$$CR_y = i_x r_A h_x h_y \sigma_{Py}$$

correlated response in trait y when selecting on trait x

selection intensity (i) for trait you are selecting on

Genetic Correlation

Square root of heritabilities

Phenotypic SD for trait with correlated response

Relative efficiency CR_y/R_y

- Response for indirect selection for a trait relative to response for direct selection for a trait

$$\frac{CR_Y}{R_Y} = \frac{i_x r_A h_x h_y \sigma_{Py} / L_x}{i_y h_y^2 \sigma_{Py} / L_y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A$$

If selection intensity and generation interval are the same:

$$\mathbf{\frac{CR_Y}{R_Y} == \frac{h_x}{h_y} r_A}$$

Example 1: Correlated Response

– Objective: increase weight in Atlantic Salmon

- R: select on weight directly
- CR, …. or select on length with a correlated response in weight

- h^2 weight = 0.09
- h^2 length = 0.16
- r_A =0.95

$$\frac{CR_Y}{R_Y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A = \frac{h_x}{h_y} r_A = \frac{\sqrt{0.16}}{\sqrt{0.09}} 0.95 = 1.27$$

Indirect Response gives 27% <u>more</u> response than direct selection

length is more heritable and correlation is strong

Example 2: Correlated Response

– Objective: increase weight in Atlantic Salmon
  - R: select on weight directly
  - CR, …. or select on length with a correlated response in weight

- h^2 weight = 0.39
- h^2 length = 0.16
- r_A =0.95

$$\frac{CR_Y}{R_Y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A = \frac{h_x}{h_y} r_A = \frac{\sqrt{0.16}}{\sqrt{0.39}} 0.95 = 0.608$$

Indirect Response gives 39% <u>less</u> response than direct selection

weight itself has a higher correlation

Example 3: Correlated Response

– Objective: increase weight in Atlantic Salmon

- R: select on weight directly
- CR, …. or select on length with a correlated response in weight

- h^2 weight = 0.09
- h^2 length = 0.16
- r_A =0.15

$$\frac{CR_Y}{R_Y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A = \frac{h_x}{h_y} r_A = \frac{\sqrt{0.16}}{\sqrt{0.09}} 0.15 = 0.20$$

Indirect Response gives 80% less response than direct selection

Correlation is too weak

What if correlation is strongly negative?

Correlated response and indirect selection
- summary -

- If traits x and y are genetically correlated, selecting on trait x will produce a correlated response in trait y

- Under some circumstances greater response in trait y can be achieved through indirect selection on trait x

Genotype x environment (G x E) interaction

- Occurs if
  - different breeds (genotypes/sires) rank differently in different environments
  - difference between breeds (genotypes/sires) is smaller or larger in different environment

i.e. the genetic correlation (r_A) between the same trait expressed in different environments is < 1

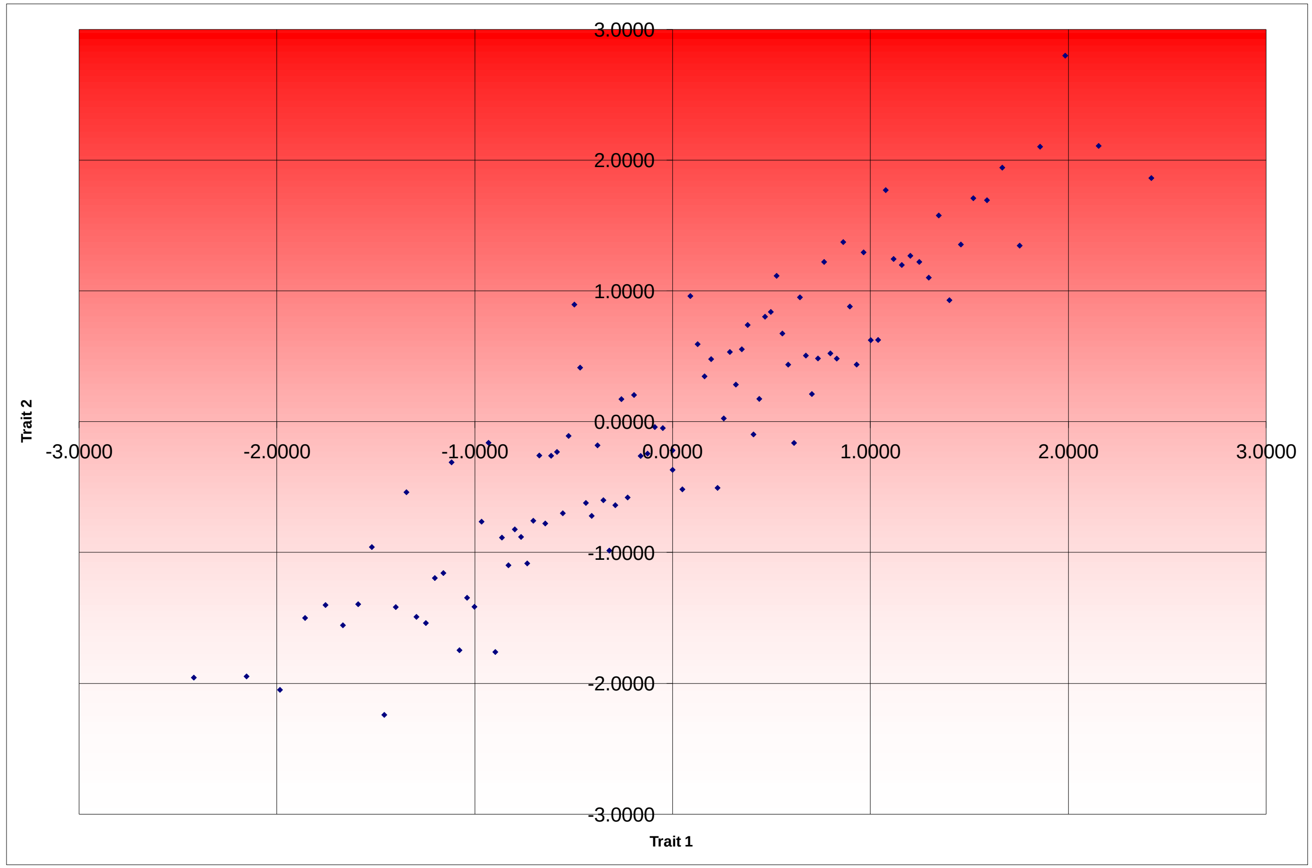
Example: yearling weight in beef cattle (hypothetical)

	Temperate	Tropical	Average
Bos. Taurus	340	230	285
Bos. Indicus	290	250	270
Average	315	240	277.5

Effect of breed depends on which environment the animals are performing

Re-ranking of animals in different environments

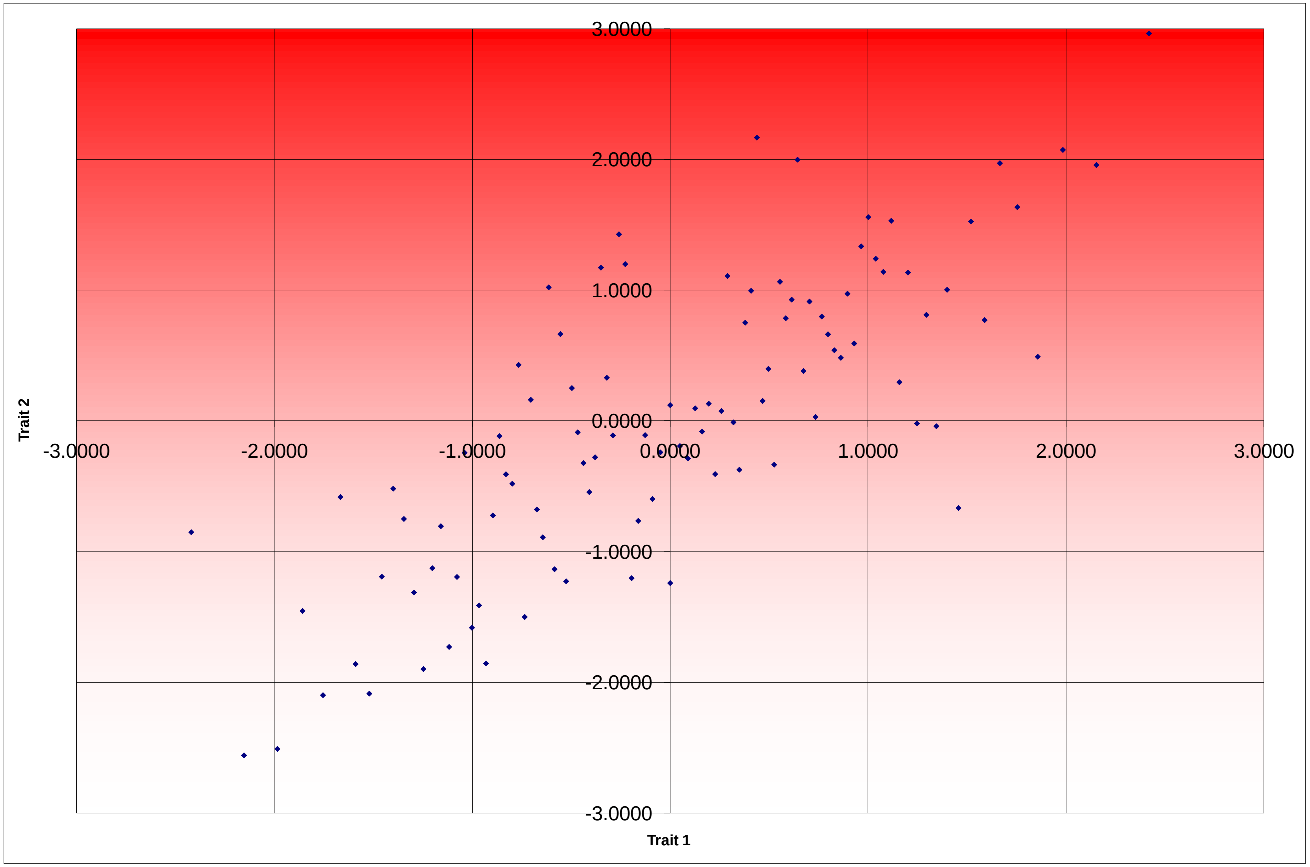
2.4209	1.8649
2.1543	2.1107
1.9854	2.8011
1.8583	2.1049
1.7550	1.3481
1.6670	1.9448
1.5898	1.6956
1.5207	1.7107
1.4578	1.3569
1.3998	0.9309
1.3459	1.5788
1.2953	1.1035
1.2476	1.2237
1.2022	1.2705
1.1590	1.2001
1.1175	1.2460
1.0777	1.7726
1.0392	0.6268
1.0020	0.6253
0.9659	1.2968
0.9307	0.4385
0.8964	0.8825
0.8629	1.3753
0.8301	0.4843
0.7979	0.5243
0.7662	1.2234
0.7351	0.4853
0.7043	0.2132
0.6740	0.5074
0.6439	0.9528
0.6141	-0.1609
0.5846	0.4381
0.5552	0.6762
0.5259	1.1173
0.4967	0.8413
0.4675	0.8047
0.4383	0.1763
0.4090	-0.0956
0.3796	0.7413
0.3500	0.5558
0.3200	0.2854
0.2897	0.5349
0.2588	0.0270
0.2273	-0.5045
0.1950	0.4802
0.1616	0.3486
0.1267	0.5946
0.0898	0.9625
0.0494	-0.5155
0.0000	-0.3666
0.0000	-0.2178
-0.0494	-0.0473
-0.0898	-0.0394
-0.1267	-0.2425
-0.1616	-0.2602
-0.1950	0.2059
-0.2273	-0.5778
-0.2588	0.1743
-0.2897	-0.6370
-0.3200	-0.9838



Correlation = 0.90

Re-ranking of animals in different environments

2.4209	2.9650
2.1543	1.9576
1.9854	2.0733
1.8583	0.4902
1.7550	1.6353
1.6670	1.9722
1.5898	0.7707
1.5207	1.5256
1.4578	-0.6676
1.3998	1.0026
1.3459	-0.0420
1.2953	0.8114
1.2476	-0.0201
1.2022	1.1341
1.1590	0.2948
1.1175	1.5307
1.0777	1.1402
1.0392	1.2407
1.0020	1.5582
0.9659	1.3351
0.9307	0.5916
0.8964	0.9731
0.8629	0.4819
0.8301	0.5397
0.7979	0.6626
0.7662	0.7979
0.7351	0.0290
0.7043	0.9129
0.6740	0.3809
0.6439	1.9989
0.6141	0.9275
0.5846	0.7852
0.5552	1.0636
0.5259	-0.3361
0.4967	0.3979
0.4675	0.1521
0.4383	2.1674
0.4090	0.9949
0.3796	0.7511
0.3500	-0.3743
0.3200	-0.0122
0.2897	1.1083
0.2588	0.0743
0.2273	-0.4080
0.1950	0.1308
0.1616	-0.0826
0.1267	0.0952
0.0898	-0.2885
0.0494	-0.1932
0.0000	0.1199
0.0000	-1.2422
-0.0494	-0.2420
-0.0898	-0.5986
-0.1267	-0.1096
-0.1616	-0.7665
-0.1950	-1.2051
-0.2273	1.1994
-0.2588	1.4282



Correlation = 0.70

Importance of G x E interactions

- Has been studied for a number of production systems
  - Parasite resistance in sheep
  - Milk production in different countries
  -
- General conclusion is that it is of little practical importance unless $r_A < 0.80$

Accounting for G x E interaction

- Animal produces in environment A, want to predict response in environment B

- Consider the expression of the trait in the two different environments as two correlated traits (as below)

Trait 1: Weight in environment 1	Trait 2: Weight in environment 2

$$CR_y = i_x r_A h_x h_y \sigma_{Py}$$

select in environment 1 →

can determine correlated response in environment 2

G x E interaction summary

- Occurs when effect of genotype depends on the environment in which animals are performing

- Can change rank or relative merit of the breed averages (and similarly individuals within the breed)