Genotype by environment interaction

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Outline

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- Genotype *A* environment ($G \times E$) interaction is said to occur when two or more genotypes are compared across different environments and their relative performances (responses to the environment) found to differ. That is, one cultivar may have the highest performance in one environment but perform poorly in others.
- $G \times E$ is a differential genotypic expression across multiple environments.
- The effect of this interaction is that the association between phenotype and genotype is reduced.

Classification of $G \times E$

- The type of $G \times E$ interaction influences the nature of the cultivar the breeder eventually releases for the production region.
- The biological basis of $G \times E$ interaction is complex by nature.
- As the number of environments (n) and number of genotypes (m) increase, the number of possible $G \times E$ interactions is given by $\frac{mn!}{m!n!}$. However, only one genotype is the best performer under all environments.

- Allard and Bradshaw classified this interaction into three common patterns using two genotypes (A, B) and two environments (E_1, E_2)
- A $G \times E$ interaction has occured when the difference in performance betweeen the two genotypes is inconsistent over environment:

$$A_1 - B_1 \neq A_2 - B_2 (or A_1 - B_1 - (A_2 - B_2) \neq 0)$$

- Basic types of interactions are:
  1. No interaction
  2. Non-crossover interaction (Qualitative interaction)
  3. Crossover interaction (Quantitative interaction)

Table 1: Demonstration of $G \times E$ interaction

Interaction type	Genotype	Environment 1	Environment 2	Difference
No interaction	Genotype A	10	14	
	Genotype B	16	20	
	Difference	6	6	
Non-crossover interaction	Genotype A	10	14	
	Genotype B	16	24	
	Difference	6	10	
Crossover interaction	Genotype A	16	14	
	Genotype B	10	20	
	Difference	-6	6	

No interaction

- A no G $\times E$ interaction occurs when one genotype (e.g., A) consistently performs better than the other genotype (B) by about the same amount across all the environments included in the test.

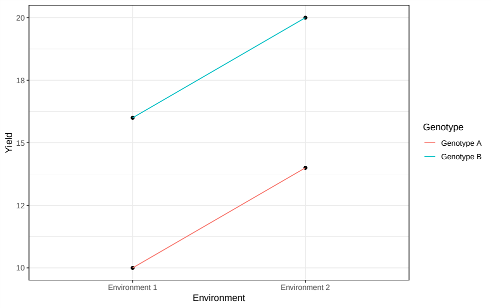
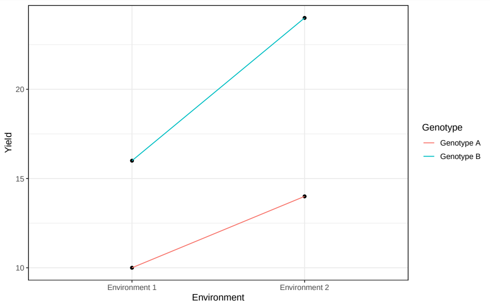


Figure 1: No interaction

Non-crossover $G \times E$ interaction

- A non-crossover $G \times E$ interaction is said to occur when a genotype (A) consistently outperforms genotype B, across the entire test environment.
- However, the differential performance is not the same across the environment. That is whereas there is no change in rank, genotype A may exceed genotype B by 20 units in one environment and 60 units another.



Crossover $G \times E$ interaction

- A crossover $G \times E$ interaction occurs when a genotype (A) is more productive in one environment, but a different genotype (B) is more productive in another environment. Most important type interaction to breeders.
- The basic test for crossover interaction is to compare the performance of two genotypes in two environments and to determine if the difference in performance is significantly less than zero in one environment and significantly greater than zero in the other.

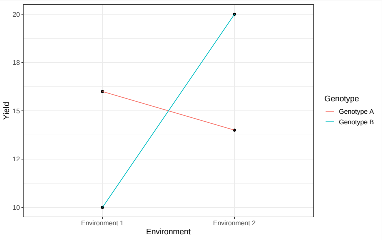


Figure 3: Crossover interaction

Combined $G \times E$ interaction

- If the one of the factors considered on the axes increases for one genotype and reduces for the other genotype, there is combined $G \times E$ interaction.

Interacting factors

- The axes in the graph may be for any relevant factor of interest to the breeder.
- For example, the x-axis may be rainfall, while the vertical axis (y) may be grain yield.
- In spite of the complexity of the environment, sometimes one factor may predominate to characterize the environment (or may be imposed by design).
- The breeder is most interested in repeatable $G \times E$ interactions.

Outline

- Interactions occur at various biological levels, such as genotypic, QTL, and phenotypic levels, the first two requiring genetic analysis.
- G x E interaction at the phenotypic level requires observations at the plant or crop level.
- The G x E interactions can also be partitioned into linear trends (e.g., G x location, G x year, G x time, etc.)
- Proper field plot designs and statistical methods are used to assess G x E interactions.
- These methods include both parametric and nonparametric procedures – partitioning of variance, regression analysis, nonparametric methods, and multivariate techniques.

ANOVA

- To ascertain the presence of G x E interaction, breeders conduct a network of comparative trials, in which prospective cultivars are compared with standard cultivars at multiple locations or agroecological regions.
- The premise for such trials, according to Mather and others is expressed by a linear equation:

$$X = \mu + g + e + ge$$

- Where:
  - X is the yield of some other quantitative traits,
  - μ is the the mean value of the population (trial),
  - g is the the value of the genotype (cultivar),
  - e is the the value of the environmental effect, and
  - ge is the the genotype x environment interaction

- Different models of ANOVA are used for partitioning variance.
- Two of the basic model categories used extensively in breeding experiments are:
  1. Fixed effects model
  2. Mixed effect model
- For a two-factor mixed model (fixed genotypes + random environment) the ANOVA table is shown in Table 2.

Table 2: Two way anova with genotypes as fixed and environment as random factors

Source	df	MS	EMS
Reps (R)	ly(r-1)		
Years (Y)	y-1		
Location (L)	l-1		
Y x L	(y-1)(l-1)		
Genotypes (G)	g-1	M_1	$\sigma_e^2 + r\sigma_{gly}^2 + rl\sigma_{gy}^2 + ry\sigma_{gl}^2 + rly\sigma_g^2$
G x Y	(g-1)(y-1)	M_2	$\sigma_e^2 + r\sigma_{gly}^2 + ry\sigma_{gl}^2 + rly\sigma_g^2$
G x L	(g-1)(l-1)	M_3	$\sigma_e^2 + r\sigma_{gly}^2 + ry\sigma_g^2 l$
G x Y x L	(g-1)(y-1)(l-1)	M_4	$\sigma_e^2 + r\sigma_{gly}^2$
Error (G x R)	(g-1)(r-1)ly	M_5	σ_e^2

Outline

- If significant genotype x location effects are observed and the rankings fluctuate by wide margins, the results indicate that the breeder should consider establishing separate breeding programs for the different locations (i.e., to develop different cultivars for different locations).
- A significant genotype x year interaction is similar in effect to genotype x location. However, because the breeder cannot develop programs for different years, a good decision would be to conduct tests over several years and select the genotype with superior average performance over the years for release. Because conducting one trial per year for more years will prolong the breeding program, the breeder may include more locations and decrease the number of years.
- The breeding implications for a complex interaction like genotype x years x location is for the breeder to select genotypes with superior average performance across locations and over years for release as new cultivars for the production region.

- Farmers will benefit from growing more than one cultivar each cropping season. This strategy will reduce the effects of the fluctuations attributed to genotype x year interaction.
- The magnitude of G x E interaction is influenced by the genetic structure of the genotype. Genotypes with less heterogeneity (e.g., pure lines, single cross hybrids, clones) or heterozygosity (e.g., pure lines) generally interact more with the environment than open-pollinated genotypes or mixtures because of lower amounts of adaptive genes.
- G x L interaction is useful for depicting adaptation patterns. Only this interaction can be exploited by selecting for specific adaptation or by growing specifically adapted genotypes. Consequently, the analysis of multiple environments yield trials should focus primarily on G x L interactions, the other interaction being considered in terms of yield stability.

Outline

References