Finlay-Wilkinson model: regression on the environmental mean

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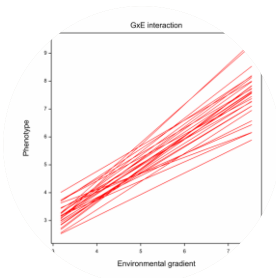
Armidale, January 2017



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Contents

- Norms of reaction
- From ANOVA model to Finlay-Wilkinson model
- Interpretation of the model parameters
  - Mean performance
  - Adaptability
  - Stability
- Example on Durum wheat Algeria

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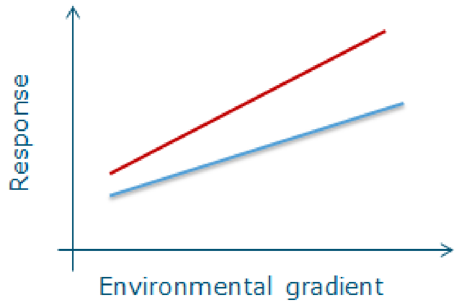
Norms of reaction

- When norms of reaction are not parallel between genotypes → GxE



Issue: What to put on the X-axis?

Finlay-Wilkinson model

THE ANALYSIS OF ADAPTATION IN A PLANT-BREEDING PROGRAMME

By K. W. Finlay* and G. N. Wilkinson†

[*Manuscript received January* 23, 1963]

Summary

The adaptation of barley varieties was studied by the use of grain yields of a randomly chosen group of 277 varieties from a world collection, grown in replicated trials for several seasons at three sites in South Australia. For each variety a linear regression of yield on the mean yield of all varieties for each site and season was computed to measure variety adaptation. In these calculations the basic yields were measured on a logarithmic scale, as it was found that a high degree of linearity was thereby induced. The mean yield of all varieties for each site and season provided a quantitative grading of the environments; and from the analysis described, varieties specifically adapted to good or poor seasons and those showing general adaptability may be identified.

Aust. J. Agric. Res., 1963, **14**, 742–54

Regression on the environmental mean (E)

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> 1400 citations

Finlay Wilkinson model

- Environmental variable = the *average yield across genotypes for each environment* (quality of environment).

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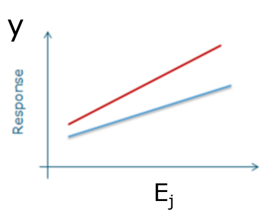
From ANOVA to Finlay Wilkinson model

$$\underline{y}_{ij} = \mu + G_i + E_j + \left(\underline{GE}_{ij} + \underline{e}_{ij}\right)$$
$$\underline{y}_{ij} = \mu + G_i + E_j + \beta_i E_j + \underline{\epsilon}_{ij}$$
$$\underline{y}_{ij} = \mu + G_i + (1 - \beta_i) E_j + \underline{\epsilon}_{ij}$$
$$\underline{y}_{ij} = \mu + G_i + \beta_i^* E_j + \underline{\epsilon}_{ij}$$



- The environmental main effect E_j is used as regressor.
- Uses environmental information **present in the data**:
  - E_j is a measure of the environmental quality,
  - … but no information of why.

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Finlay Wilkinson model

- Environmental variable = the *average yield across genotypes for each environment* (quality of environment).

- $\underline{y}_{ij} = \mu + G_i + \beta_i^* E_j + \underline{\epsilon}_{ij}$

- A popular method for estimating adaptability
  - Slope (β*) of this regression is a measure for adaptability
  - Intercept (μ + G_i) is a measure for general performance
- The average slope =1
  - genotypes with slopes > 1 have higher than average adaptability
  - genotypes with slopes < 1 have lower than average adaptability

Notation:

In the following, β is β*

(i.e. we drop the * from the notation for simplicity)

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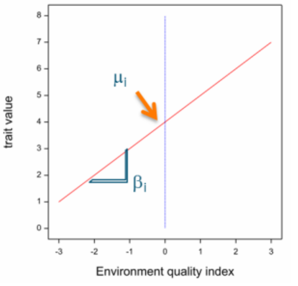
Finlay-Wilkinson model parameters

$$\underline{y}_{ij} = \mu + G_i + \beta_i E_j + \underline{\varepsilon}_{ij}$$

$$\underline{y}_{ij} = \mu_i + \beta_i E_j + \underline{\varepsilon}_{ij}$$



- μ_i (intercept): the expected performance of genotype i in the "average" environment.
- β_i (slope) = the sensitivity of genotype i to the improvement in the quality of the environment (adaptability).

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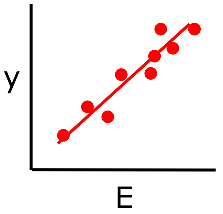
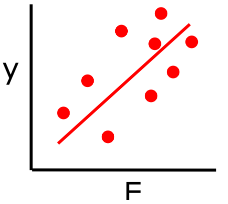
Finlay Wilkinson model and stability

- Eberhart and Russell stability (type 3): deviation from predicted performance given environment
  - stable genotype = low residual variance ($\sigma^2_{\varepsilon_{ij}}$) from the regression line (predicted response).



Stable, $\sigma^2_{\varepsilon_{ij}}$ is small



Unstable, $\sigma^2_{\varepsilon_{ij}}$ is large

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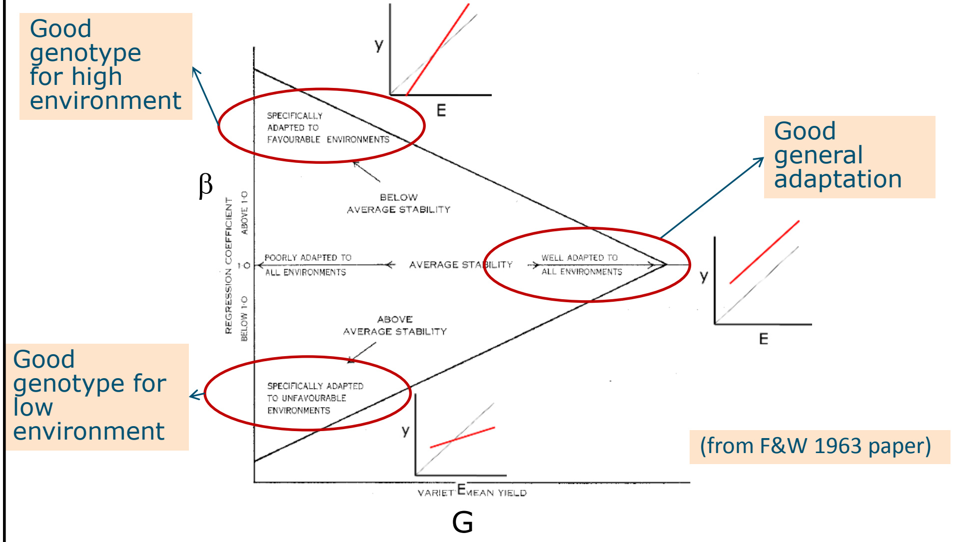
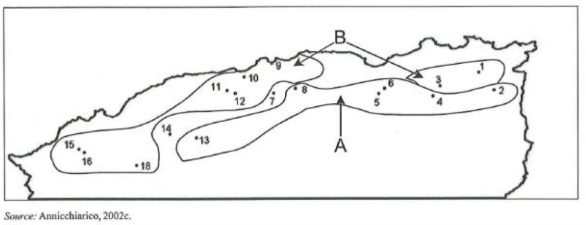
FW parameters plotted together



Example durum wheat Algeria



Source: Annicchiarico, 2002c.

- 24 genotypes
- 22 trials (environments), each one designed as RCBD.
  - 11 sites
  - 2 years
- Grain yield (ton/ha)

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Data set: two-way table of means

Environments →

Genotypes ↓

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Geno!	s01_y1	s01_y2	s02_y1	s02_y2	s04_y1	s04_y2	s05_y1	s05_y2	s07_y1	s07_y2	s10_y1	s10_y2	s11_y1	s11_y2	s12_y1	s12_y2	s14_y1	s14_y2	s16_y1	s16_y2	s18_y1	s18_y2
2	ARDENTE	3.641	2.462	2.485	0.715	1.894	1.217	1.087	1.662	0.961	0.646	1.424	1.819	1.065	2.189	2.267	2.286	2.365	3.14	0.905	1.649	1.509	1.648
3	B.DUR194	3.626	2.544	2.352	1.625	2.119	1.132	1.269	1.828	1.092	0.854	1.61	2.574	1.271	2.771	2.181	2.982	2.311	3.302	1.273	1.73	1.577	1.667
4	BELIKH02	3.597	2.809	2.722	1.282	1.871	1.185	1.29	1.684	1.078	0.612	1.824	2.417	1.604	1.891	2.44	2.299	2.31	3.189	1.894	1.716	1.26	1.578
5	BID/WAHA	3.415	3.036	2.388	1.174	2.175	1.124	1.201	1.694	1.047	0.658	1.813	2.638	2.015	2.092	2.66	2.835	2.298	3.238	1.694	1.813	1.791	1.668
6	BIDI17	2.686	2.146	2.232	1.011	1.847	1.149	1.09	1.613	0.977	0.53	1.32	1.756	1.552	2.201	2.143	2.452	2.099	3.207	0.91	1.542	0.884	1.728
7	CHENS	3.632	3.139	2.519	1.157	2.132	1.137	1.461	1.868	1.292	0.882	1.693	2.73	1.854	2.031	2.603	2.752	2.292	3.301	1.858	1.364	1.746	1.79
8	DUILIO	3.324	3.187	2.233	1.789	2.048	1.078	1.133	1.787	1.119	0.784	1.498	2.584	1.756	1.996	2.715	2.771	2.133	3.15	1.78	1.305	1.518	1.709
9	EIDER	3.524	2.65	2.387	1.056	1.931	1.117	1.261	1.85	1.201	0.715	1.86	2.366	1.621	2.182	2.299	2.319	2.204	3.189	1.569	1.434	2.023	1.681
10	GTADUR	3.924	3.005	2.561	1.202	2.361	1.332	1.275	1.921	1.074	0.86	1.841	2.689	1.508	2.043	2.894	2.877	2.31	3.266	1.53	1.715	1.851	1.813
11	HEBD/GD	3.276	2.721	2.271	0.897	2.009	1.086	0.97	1.676	1.069	0.633	1.634	1.82	1.21	1.65	2.604	2.454	2.27	3.114	0.999	1.286	1.027	1.734
12	HEBDA03	2.472	1.679	2.057	0.981	1.79	1.064	0.939	1.635	0.969	0.325	1.411	1.688	0.864	2.161	2.085	2.453	2.17	3.028	1.393	1.379	1.316	1.713
13	INRAT69	3.103	2.7	2.071	1.029	1.92	1.07	0.683	1.349	1.075	0.726	1.411	2.051	1.667	1.982	2.353	2.823	2.212	3.11	1.629	1.38	1.944	1.566
14	KEBIR	3.051	2.774	2.396	1.268	1.977	1.139	0.86	1.535	1.001	0.629	1.581	2.398	1.503	1.795	2.507	2.578	2.241	3.141	1.65	1.475	1.277	1.531
15	MBBACHI	2.795	1.438	2.278	1.181	1.887	1.022	0.988	1.637	1.089	0.299	1.411	1.479	1.062	1.629	2.149	2.173	2.379	3.095	1.253	1.116	1.377	1.708
16	MEXICALI	3.103	3.32	2.104	0.801	2.082	1.019	1.264	1.655	1.137	0.713	1.909	2.056	2.065	2.289	2.53	2.68	2.32	3.262	2.171	1.783	1.389	1.668
17	O.ZENADI	2.621	1.467	2.171	0.821	1.811	1.15	1.091	1.665	0.987	0.448	1.52	1.388	1.196	1.522	2.115	2.162	2.233	3.166	0.856	1.573	1.012	1.669
18	OFANTO	3.364	3.114	2.808	1.067	2.309	1.237	1.31	1.993	1.294	0.865	1.529	1.934	1.451	1.869	2.419	2.666	2.275	3.055	1.906	1.838	1.91	1.567
19	OUMRABI	3.604	2.791	2.212	1.246	2.195	1.184	1.227	1.675	1.21	0.844	1.493	2.521	1.702	1.821	2.493	2.421	2.369	3.094	1.48	1.508	1.919	1.661
20	POLON/Z	2.829	1.954	2.191	1.05	1.821	1.113	1.099	1.655	1.006	0.503	1.473	1.752	1.076	2.185	2.171	2.339	2.271	3.177	0.888	1.238	1.041	1.715
21	POLONIC	2.592	1.683	2.098	1.49	2.054	1.131	1.001	1.758	1.181	0.524	1.45	1.707	0.937	2.191	1.88	2.506	2.174	3.038	0.905	1.433	1.77	1.613
22	SAHEL77	3.578	3.081	2.508	1.4	2.037	1.17	1.404	1.723	0.966	0.718	1.73	2.332	1.521	2.6	2.933	2.315	2.237	3.234	2.424	1.32	2.749	1.7
23	SIMETO	3.075	3.387	2.47	1.233	2.478	1.005	0.845	1.679	1.238	0.741	1.839	2.864	1.962	2.384	2.837	2.218	2.285	3.244	1.58	1.397	1.697	1.878
24	VITRON	3.404	3.286	2.321	0.72	1.92	1.105	1.176	1.717	1.208	0.681	1.804	2.364	1.632	2.596	2.622	2.446	2.114	3.178	1.894	1.387	1.951	1.709
25	WAHA	3.483	3.103	2.481	0.826	2.155	1.127	1.299	1.64	0.98	0.755	1.647	2.449	1.891	2.111	2.406	2.835	2.274	3.137	1.907	1.571	2.215	1.721

- Environment = Soil properties, weather conditions, incidence pest/diseases, etc...
- E = Mean performance in a particular environment

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Environmental index

- Environmental variable = Environmental main effect (E_j).
  - As a deviation from the average

$$\underline{y}_{ij} = \mu + G_i + E_j + (\underline{GE}_{ij} + \underline{e}_{ij})$$

- Environments can be ranked on E:
  - E > 0: better than average
  - E < 0: worse than average

- E = "Environmental Index"

env	E
s01_y1	1.3736
s14_y2	1.2801
s01_y2	0.7984
s12_y2	0.6474
s12_y1	0.5603
s02_y1	0.4688
s14_y1	0.3721
s10_y2	0.3238
s11_y2	0.2137
s04_y1	0.1575
s05_y2	-0.1759
s18_y2	-0.1951
s18_y1	-0.2540
s10_y1	-0.2587
s16_y1	-0.3489
s11_y1	-0.3641
s16_y2	-0.3775
s05_y1	-0.7386
s04_y2	-0.7470
s02_y2	-0.7532
s07_y1	-0.7825
s07_y2	-1.2001

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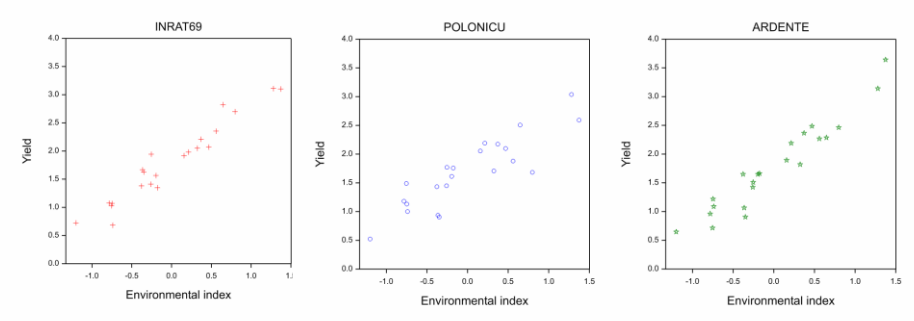
Yield versus environmental index (E)



- Three genotypic responses
  - Differences / similarities?

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FW model for genotype POLONICU

Interpretation of the model parameters?

Regression analysis

Response variate: yld[20]
Fitted terms: Constant, EnvIndex

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.
Regression	1	6.080	6.08032	67.32
Residual	20	1.806	0.09032	
Total	21	7.887	0.37556	

var(ε)

Percentage variance accounted for 76.0
Standard error of observations is estimated to be 0.301.

Message: the following units have large standardized residuals.

Unit	Response	Residual
2	1.683	-2.24

Message: the following units have high leverage.

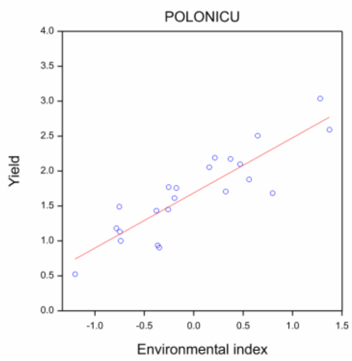
Unit	Response	Leverage
1	2.592	0.239
10	0.524	0.193
18	3.038	0.214

Estimates of parameters

Parameter	estimate	s.e.	t(20)
Constant	1.6871	0.0641	26.33
EnvIndex	0.7897	0.0962	8.20

μ_i

β



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POLONICU vs ARDENTE

ARDENTE higher stability (smaller var(ε))

ARDENTE (slightly) higher general adaptation (μ_i)

ARDENTE higher adaptability (β)

POLONICU

Regression analysis

Resp

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.
Regression	1	6.080	6.08032	67.32
Residual	20	1.806	0.09032	
Total	21	7.887	0.37556	

Percentage variance accounted for 76.0
Standard error of observations is estimated to be 0.301.

Message: the f

Unit		
2	1.683	-2.24

Message: the following units have high leverage.

Unit	Response	Leverage
1	2.592	0.239
10	0.524	0.193
18	3.038	0.214

Estimates of parameters

Parameter	estimate	s.e.	t(20)
Constant	1.6871	0.0641	26.33
EnvIndex	0.7897	0.0962	8.20

ARDENTE

Regression analysis

ex

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.
Regression	1	11.671	11.67059	225.58
Residual	20	1.035	0.05174	
Total	21	12.705	0.60501	

Percentage variance accounted for 91.4
Standard error of observations is estimated to be 0.227.

iduals.

19	0.905	-2.21

Message: the following units have high leverage.

Unit	Response	Leverage
1	3.641	0.239
10	0.646	0.193
18	3.140	0.214

Estimates of parameters

Parameter	estimate	s.e.	t(20)
Constant	1.7744	0.0485	36.59
EnvIndex	1.0940	0.0728	15.02

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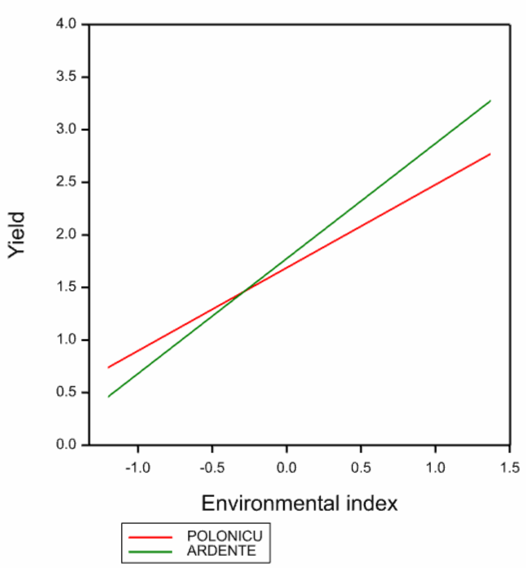
ARDENTE better than POLONICU ?



It depends!
In high quality environments yes, but not in low quality environments…

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From ANOVA to FW model

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Geno	23	13.47438	0.58584	10.34	<.001
+ Env	21	233.96713	11.14129	196.63	<.001
Residual	483	27.36739	0.05666		
Total	527	274.80890	0.52146		

Analysis of variance

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Genotypes	23	13.4744	0.5858	10.51	<0.001
Environments	21	233.9671	11.1413	199.95	<0.001
Sensitivities	23	1.7364	0.0755	1.35	0.127
Residual	460	25.6310	0.0557		
Total	527	274.8089	0.5215		

- Partition of the ANOVA "residual" (GxE+error) into:
  - Heterogeneity of slopes (="sensitivities")
  - Residual
- (a little) part of the GxE has become predictable

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Full results

$$\underline{y}_{ij} = \mu_i + \beta_i E_j + \varepsilon_{ij}$$

- What would happen with these parameters if we remove some of the genotypes?

Sorted sensitivity estimates

Genotype	Sensitivity β	s.e.	Mean μ_i	s.e.	Var(ε) Mean square deviation
1) POLONICU	0.7897	0.07559	1.687	0.05033	0.09032
2) O.ZENADI	0.8336	0.07559	1.575	0.05033	0.09884
3) HEBDA03	0.8628	0.07559	1.617	0.05033	0.06455
4) MBBACHIR	0.8679	0.07559	1.611	0.05033	0.08581
5) BIDI17	0.9206	0.07559	1.685	0.05033	0.05923
6) POLON/ZB	0.9407	0.07559	1.661	0.05033	0.05514
7) OFANTO	0.9724	0.07559	1.990	0.05033	0.04635
8) EIDER	0.9863	0.07559	1.929	0.05033	0.02086
9) OUMRABI9	0.9935	0.07559	1.940	0.05033	0.02562
10) INRAT69	1.0092	0.07559	1.812	0.05033	0.03523
11) MEXICALI	1.0138	0.07559	1.969	0.05033	0.07472
12) DUILIO	1.0158	0.07559	1.973	0.05033	0.05176
13) KEBIR	1.0223	0.07559	1.832	0.05033	0.02185
14) SAHEL77	1.0292	0.07559	2.076	0.05033	0.11352
15) BELIKH02	1.0326	0.07559	1.934	0.05033	0.03979
16) B.DUR194	1.0464	0.07559	1.986	0.05033	0.06401
17) CHENS	1.0647	0.07559	2.056	0.05033	0.02646
18) WAHA	1.0663	0.07559	2.001	0.05033	0.04165
19) SIMETO	1.0685	0.07559	2.015	0.05033	0.07589
20) BID/WAHA	1.0694	0.07559	2.021	0.05033	0.02367
21) HEBD/GDO	1.0752	0.07559	1.746	0.05033	0.04052
22) VITRON	1.0812	0.07559	1.965	0.05033	0.04987
23) ARDENTE	1.0940	0.07559	1.774	0.05033	0.05174
24) GTADUR	1.1395	0.07559	2.084	0.05033	0.02416

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Summary: Finlay-Wilkinson model

- In FW-regression the environments is the mean performance of all genotypes in that environment (E)
- Genotypes are characterized in terms of:
  - intercept (general performance, μ_i)
  - slope (adaptability, β)
  - deviations from regression (stability, var(ε))
- Prediction of variety performance in unobserved environment is possible when E is known

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