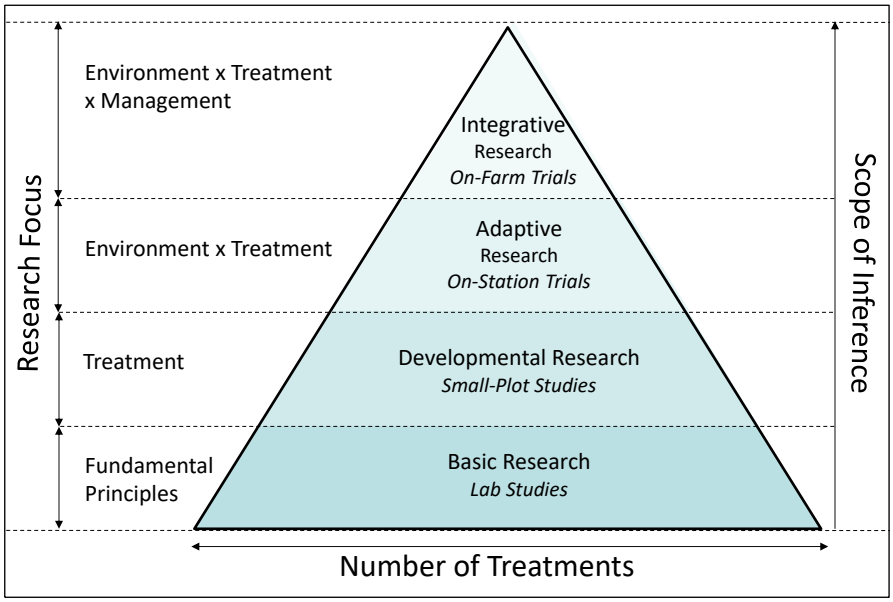
Research Strategies and Environmental Replication



Environmental Replication

Multiple Locations

Linear additive model:

$$Y_{ijk} = \mu + L_i + B_{(i)j} + \delta_{(ij)} + T_k + LT_{ik} + BT_{(i)jk}$$

Where:

- Y_{ijk} = variable to be analyzed from the ijk^{th} e.u. (plot)
- μ = overall mean
- L_i = effect of i^{th} location
- $B_{(i)j}$ = effect of j^{th} block within the i^{th} location
- $\delta_{(ij)}$ = restriction error associated with blocks within locations
- T_k = effect of k^{th} treatment
- LT_{ik} = interaction effect i^{th} level of L with the k^{th} level of T
- $BT_{(i)jk}$ = experimental error, NID(0,σ^2)

Environmental Replication
Multiple Locations

Source	Locations random	Locations fixed
L_i	$\sigma^2 + t\sigma^2_\delta + t\sigma^2_B + bt\sigma^2_L$	$\sigma^2 + t\sigma^2_\delta + t\sigma^2_B + bt\Phi(L)$
$B_{(i)j}$	$\sigma^2 + t\sigma^2_\delta + t\sigma^2_B$	$\sigma^2 + t\sigma^2_\delta + t\sigma^2_B$
$\delta_{(ij)}$	$\sigma^2 + t\sigma^2_\delta$	$\sigma^2 + t\sigma^2_\delta$
T_k	$\sigma^2 + \sigma^2_{BT} + b\sigma^2_{LT} + lb\Phi(T)$	$\sigma^2 + \sigma^2_{BT} + lb\Phi(T)$
LT_{ik}	$\sigma^2 + \sigma^2_{BT} + b\sigma^2_{LT}$	$\sigma^2 + \sigma^2_{BT} + b\Phi(LT)$
$BT_{(i)jk}$	$\sigma^2 + \sigma^2_{BT}$	$\sigma^2 + \sigma^2_{BT}$

Environmental Replication
Multiple Years – Annual Crops

Linear additive model:

$$Y_{ijk} = \mu + Y_i + B_{(i)j} + \delta_{(ij)} + T_k + YT_{ik} + BT_{(i)jk}$$

Where:

- Y_{ijk} = variable to be analyzed from the ijk^{th} e.u. (plot)
- μ = overall mean
- Y_i = effect of i^{th} year
- $B_{(i)j}$ = effect of j^{th} block within the i^{th} year
- $\delta_{(ij)}$ = restriction error associated with blocks within years
- T_k = effect of k^{th} treatment
- YT_{ik} = interaction effect i^{th} level of Y with the k^{th} level of T
- $BT_{(i)jk}$ = experimental error, NID(0, σ^2)

Environmental Replication

Multiple Years – Annual Crops

Expected Mean Squares

Source	EMS
Y_i	$\sigma^2 + t\sigma^2_{\delta} + t\sigma^2_B + bt\sigma^2_Y$
$B_{(i)j}$	$\sigma^2 + t\sigma^2_{\delta} + t\sigma^2_B$
$\delta_{(ij)}$	$\sigma^2 + t\sigma^2_{\delta}$
T_k	$\sigma^2 + \sigma^2_{BT} + b\sigma^2_{YT} + yb\Phi(T)$
YT_{ik}	$\sigma^2 + \sigma^2_{BT} + b\sigma^2_{YT}$
$BT_{(i)jk}$	$\sigma^2 + \sigma^2_{BT}$

Environmental Replication

Fixed Years – Perennial Crops

Linear additive model:

$$Y_{ijk} = \mu + B_i + \delta_{(i)} + T_j + \varepsilon_{ij} + \omega_{(ij)} + Y_k + TY_{jk} + \varepsilon_{ijk}$$

Where:

- Y_{ijk} = variable to be analyzed from the ijk^{th} e.u. (plot)
- μ = overall mean
- B_i = effect of i^{th} block
- $\delta_{(i)}$ = restriction error associated with blocks
- T_j = effect of j^{th} treatment
- e_{ij} = error a, NID(0, σ^2)
- $\omega_{(i)}$ = restriction error associated with plots
- Y_k = effect of k^{th} year
- TY_{jk} = interaction effect of j^{th} level T with the k^{th} level of Y
- ε_{ijk} = error b, NID(0, σ^2)

Environmental Replication

Fixed Years – Perennial Crops

Expected Mean Squares

Source	EMS
B_i	$y\sigma^2_\omega + ty\sigma^2_\delta + ty\sigma^2_B$
$\delta_{(i)}$	$y\sigma^2_\omega + ty\sigma^2_\delta$
T_j	$y\sigma^2_\omega + y\sigma^2_b + by\sigma(T)$
ε_{ij}	$y\sigma^2_\omega + y\sigma^2_b$
$\omega_{(ij)}$	$y\sigma^2_\omega$
Y_k	$\sigma^2_a + bt\Phi(Y)$
TY_{jk}	$\sigma^2_a + b\Phi(TY)$
ε_{ijk}	σ^2_a

Environmental Replication

Multiple Years and Locations

State	Year	Environment
IA	1998	1
IA	1999	2
NE	1999	3
SD	1998	4
SD	1999	5
WI	1998	6

Environmental Replication
Multiple Years and Locations

Linear additive model:

$$Y_{ijkl} = \mu + Y_i + L_j + YL_{ij} + B_{(ij)k} + \delta_{(ijk)} + T_l + YT_{il} + LT_{jl} + YLT_{ijl} + BT_{(ij)kl}$$

Where:

- Y_{ijkl} = variable to be analyzed from the ijklth e.u. (plot)
- μ = overall mean
- Y_i = effect of ith year
- L_j = effect of jth location
- YL_{ij} = interaction effect jth of level Y with the jth level of L
- $B_{(ij)k}$ = effect of kth block within the ith year and jth location
- T_l = effect of lth treatment
- YT_{il} = interaction effect ith of level Y with the lth level of T
- LT_{jl} = interaction effect jth of level L with the lth level of T
- YLT_{ijl} = interaction effect ith of level Y, jth level of L, and lth level of T
- $BT_{(ij)kl}$ = interaction effect kth of level B with lth level of T

Environmental Replication
Multiple Years and Locations

Source	df	MS	F-tests	
			RY-RL	RY-FL
Year	y - 1	M_1	M_1/M_3	M_1/M_4
Location	l - 1	M_2	M_2/M_3	M_2/M_3
Y x L	(y – 1)(l – 1)	M_3	M_3/M_4	M_3/M_4
Block / Y x L	(r – 1)yl	M_4		
Treatment	t - 1	M_5	No test	M_5/M_6
T x Y	(t – 1)(y – 1)	M_6	M_6/M_8	M_6/M_9
T x L	(t – 1)(l – 1)	M_7	M_7/M_8	M_7/M_8
T x Y X L	(t – 1)(y – 1)(l – 1)	M_8	M_8/M_9	M_8/M_9
Error	(r – 1)(t – 1)yl	M_9		

See McIntosh, 1983.

Environmental Replication

Multiple Years and Locations – Alternative Tests

Source	df	MS	F-tests	
			RY-RL	RY-FL
Year	y - 1	M_1	No test	No test
Location	l - 1	M_2	No test	M_2/M_3
Y x L	(y – 1)(l – 1)	M_3	No test	No test
Block / Y x L	(r – 1)yl	M_4		
Treatment	t - 1	M_5	No test	M_5/M_6
T x Y	(t – 1)(y – 1)	M_6	M_6/M_8	M_6/M_8
T x L	(t – 1)(l – 1)	M_7	M_7/M_8	M_7/M_8
T x Y X L	(t – 1)(y – 1)(l – 1)	M_8	M_8/M_9	M_8/M_9
Error	(r – 1)(t – 1)yl	M_9		

Alternative mixed model assumptions. All mixed interactions considered random.

Environmental Replication

Potential Issues

Heterogeneous errors among environments:

- Analyze by location
- Transformed data, or
- Mixed model approach

Heterogeneous treatment x environment interaction:

- Partition into stable and unstable treatments and analyze separately
- Subset in Mixed analysis

Environmental Replication
Pinto Bean Variety Trial Example

Treatment Factors:

Year (Yr) 3
- 1990
- 1991
- 1992

Location (Loc) 2
- Erie
- Lupton

Block (Blk) 3

Variety (Var) 5
- CO24
- CO66
- CO88
- JB505
- JB66

Environmental Replication
Pinto Bean Variety Trial Example

Layout:

Year:	1990						1991						1992					
Location:	Erie			Lupton			Erie			Lupton			Erie			Lupton		
Block:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Variety: CO24																		
CO66																		
CO88																		
JB505																		
JB66																		

Environmental Replication
Pinto Bean Variety Trial Example

Linear additive model:

$Y_{ijk} = \mu + Y_i + L_j + YL_{ij} + B_{(ij)k} + \delta_{(ijk)} + V_l + YV_{il} + LV_{jl} + YLV_{ijl} + BV_{(ij)kl}$

Environmental Replication
Pinto Bean Variety Trial Example

Term	df	i R 3	j F 2	k R 3	l F 5	Expected Mean Square	
Y_i	2	1	2	3	5	M1:	$5\sigma^2_B + 30\sigma^2_Y$
L_j	1	3	0	3	5	M2:	$5\sigma^2_B + 15\sigma^2_{YL} + 45\Phi[L]$
YL_{ij}	2	1	0	3	5	M3:	$5\sigma^2_B + 15\sigma^2_{YL}$
$B_{(ij)k}$	12	1	1	1	5	M4:	$5\sigma^2_B$
V_l	4	3	2	3	0	M5:	$\sigma^2_{BV} + 6\sigma^2_{YV} + 18\Phi[V]$
YV_{il}	8	1	2	3	0	M6:	$\sigma^2_{BV} + 6\sigma^2_{YV}$
LV_{jl}	4	3	0	3	0	M7:	$\sigma^2_{BV} + 3\sigma^2_{YLV} + 9\Phi[LV]$
YLV_{ijl}	8	1	0	3	0	M8:	$\sigma^2_{BV} + 3\sigma^2_{YLV}$
$BV_{(ij)kl}$	48	1	1	1	0	M9:	σ^2_{BV}

Test for Homogeneity

Hartley's F-max Test

Year	Location	MS
1990	Erie	9.650
1990	Lupton	25.533
1991	Erie	5.7833
1991	Lupton	10.033
1992	Erie	5.283
1992	Lupton	17.850

Hartley's F-max Test

$$F_{max} = \frac{\max\left\{\hat{\sigma}_i^2\right\}}{\min\left\{\hat{\sigma}_i^2\right\}} = \frac{25.533}{5.283} = 4.833$$

$F_{(.01,6,8)} = 6.37$

Therefore, do not reject H_0

Environmental Replication

Pinto Bean Variety Trial Example

```
proc glm;
  class yr loc blk var;
  model yield = yr loc yr*loc blk(yr*loc)
     var yr*var loc*var yr*loc*var / ss3;
  test h=yr yr*loc e=blk(yr*loc);
  test h=loc e=yr*loc;
  test h=var e=yr*var;
  test h=loc*var e=yr*loc*var;
  lsmeans yr*loc*var / slice=var;
run;
```

Environmental Replication

Pinto Bean Variety Trial Example

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	41	6791.39	165.644	13.41	<.0001
Error	48	593.067	12.3556		
Corrected Total	89	7384.46			

R-Square	Coeff Var	Root MSE	Yield Mean
0.919687	8.15977	3.51505	43.0778

Environmental Replication

Pinto Bean Variety Trial Example

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Yr	2	3570.02	1785.01	144.47	<.0001
Loc	1	380.278	380.278	30.78	<.0001
Yr*Loc	2	66.2889	33.1444	2.68	0.0786
Blk(Yr*Loc)	12	232.267	19.3556	1.57	0.1340
Var	4	2164.51	541.128	43.8	<.0001
Yr*Var	8	339.756	42.4694	3.44	0.0033
Loc*Var	4	15.8889	3.97222	0.32	0.8622
Yr*Loc*Var	8	22.3778	2.79722	0.23	0.9843

Blue model terms tested by residual error [Var*Blk(Yr*Loc)]

Environmental Replication
Pinto Bean Variety Trial Example

Tests of Hypotheses Using the Type III MS for Blk(Yr*Loc) as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Yr	2	3570.02	1785.01	92.22	<.0001
Yr*Loc	2	66.2889	33.1444	1.71	0.2217

Tests of Hypotheses Using the Type III MS for Yr*Loc as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Loc	1	380.278	380.278	11.47	0.0772

Environmental Replication
Pinto Bean Variety Trial Example

Tests of Hypotheses Using the Type III MS for Yr*Var as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Var	4	2164.51	541.128	12.74	0.0015

Tests of Hypotheses Using the Type III MS for Yr*Loc*Var as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Loc*Var	4	15.8889	3.97222	1.42	0.3112

Environmental Replication

Pinto Bean Variety Trial Example

Yr*Var Effect Sliced by Var for Yield

Var	DF	Sum of Squares	Mean Square	F Value	Pr > F
CO24	2	385.444	192.722	15.60	<.0001
CO66	2	470.777	235.388	19.05	<.0001
CO88	2	914.111	457.055	36.99	<.0001
JB505	2	727.111	363.555	29.42	<.0001
JB66	2	1412.333	706.166	57.15	<.0001

Environmental Replication

Pinto Bean Variety Trial Example