Repeated Measures

Common Agronomic Examples

Experiment Type:

- Perennial crops
  Forages, Horticultural crops
- Crop rotations
  Cumulative effects of crop sequences
- Long-term experiments
  Experiments repeated over many years at same sites

In each of these cases, observations are made over time from the same experimental unit (plot).

The fixed year effect of the treatment is confounded with random growing season effects (weather, pests) and may not be independent from the plot effect.

Perennial Crop Experiments

- Perennial crops are those that survive and are harvested over multiple years
  - Forage and pasture crops are common agronomic examples
  - Fruit crops are a common horticultural example
- Perennial crops generally go through an establishment phase before reaching full productivity; length of this phase varies with crop but may last several years
- The effect of time, often measured in years, is generally of interest; it represents the age of the crop
- Measurements made over time are usually made from the same experimental unit (the subject to which the treatment was applied) and thus may be correlated

Perennial Crop Experiments

Pasture Legume Trial Example

Objective:

Evaluate twelve complementary grazing systems over a five-year period.

System	Spring	Summer	Fall
1	Smooth bromegrass	→ → →	
2		→	→
3	Alfalfa	→	→
4		→ → →	
5		→	→
6		→	→
7		→ → →	
8		→	→
9		→	→
10		→ → →	
11		→	→
12		→	→

Perennial Crop Experiments

Pasture Legume Trial Example

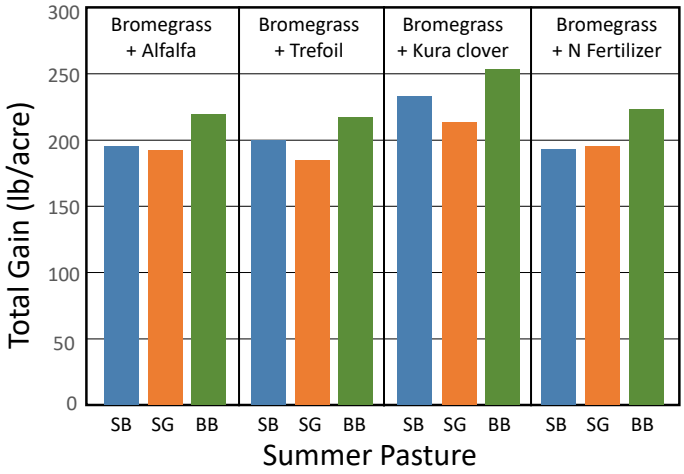
Analysis of Variance

```
proc mixed;
  class System Year;
  model TotGain = System Year Year*System;
  repeated year / subject=Rep*System type=cs r rcorr;
  lsmeans Year*System / slice=(System Year);
run;
```

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
System	11	120	8.82	<.0001
Year	4	120	82.04	<.0001
System*Year	44	120	1.57	0.0290

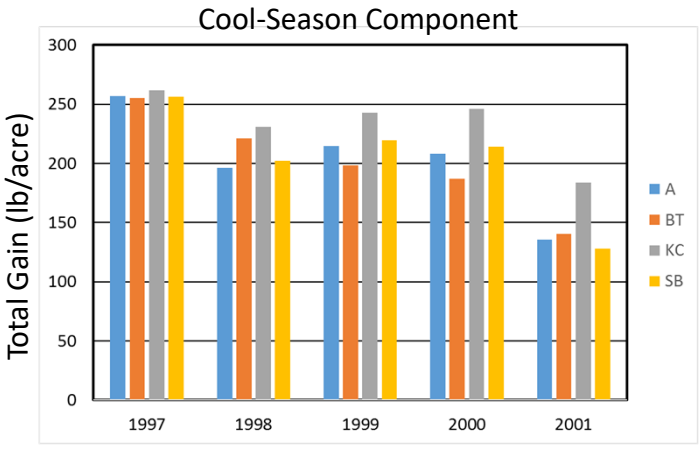
Perennial Crop Experiments

Pasture Legume Trial Example



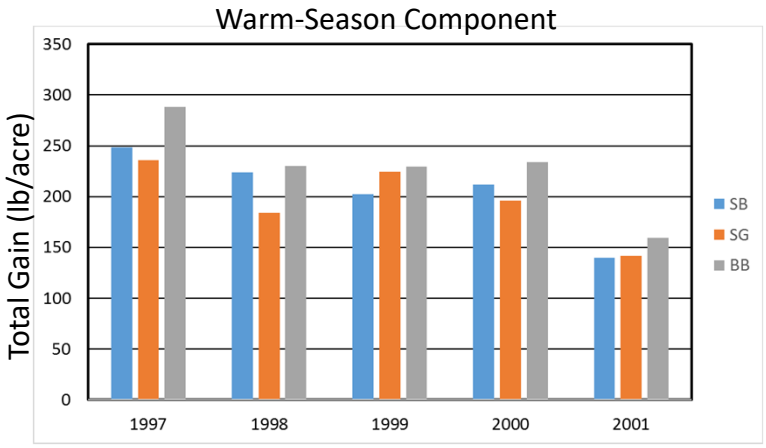
Perennial Crop Experiments

Pasture Legume Trial Example



Perennial Crop Experiments

Pasture Legume Trial Example



Crop Rotation Experiments

Definitions and Concepts

Crop Rotation
- Sequence of crops repeated over several years at the same location

Course
- Individual crop within a rotation

Cycle
- The number of times the rotation has been repeated; each cycle represents one complete sequence in the rotation

Phase
- The current crop in a rotation

Period
- The number of possible phases

Definitions adapted from Preece, 1986.

Crop Rotation Experiments

Examples

Crop Rotation
- Corn-Corn-Soybean

Course
- Either corn or soybean

Cycle
- Starting in year four, the rotation will be in the second cycle
- Starting in year seven, the rotation will be in the third cycle

Phase
- There are three phases: 1) corn after soybean; 2) corn after corn; and 3) soybean after corn

Period
- Three

Definitions adapted from Preece, 1986.

Crop Rotation Experiments

Three General Types

Short-Term
- Only one complete cycle is completed
- Usually followed by a common test crop

Fixed-Rotation
- Assesses the effect of other treatments within a single crop rotation

Multi-Rotation
- Compares several rotation sequences over time
- Generally long-term experiments with multiple cycles of each rotation
- Presents the most logistical and statistical challenges

Crop Rotation Experiments

Multi-Rotation Experiments

Crop Rotation:

- Sequences of crops repeated over several years at the same location
- Treatment effects are cumulative over time
  - The treatment is augmented each year
  - In any year, treatments are the combined effects of the current and previous crops in the rotation
- Annual measurements are repeated on the same plot and thus potentially correlated
- Year effects associated with crop sequence are confounded with random effects of weather

Crop Rotation Experiments

Dryland Cropping System Example (Lenssen et al.)

Objective:

Compare the effects of four dryland cropping systems on soil organic carbon (Mg/ha) over a period of four years.

Systems:

Wheat – Barley – Corn – Pea
Wheat – Barley – Pea
Wheat – Pea
Continuous Wheat

Measures:

2004, 2005, 2006, 2007

Crop Rotation Experiments

Dryland Cropping System Example (Lenssen et al.)

Design:

RCBD with 3 reps

Treatments:

1. Continuous Wheat
2. W-B-C-P Barley
3. W-B-C-P Corn
4. W-B-C-P Pea
5. W-B-C-P Wheat
6. W-B-P Barley
7. W-B-P Pea
8. W-B-P Wheat
9. W-P Pea
10. W-P Wheat

Crop Rotation Experiments

Dryland Cropping System Example

Analysis of Variance

```
proc mixed;
  class rep treatment year;
  model OC = treatment year treatment*year;
  random rep rep*treatment;
  lsmeans treatment*year / slice=(treatment year);
run;
```

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Treatment	9	18	0.77	0.6433
Year	3	95	6.95	0.0003
Treatment*Year	27	95	1.09	0.3709

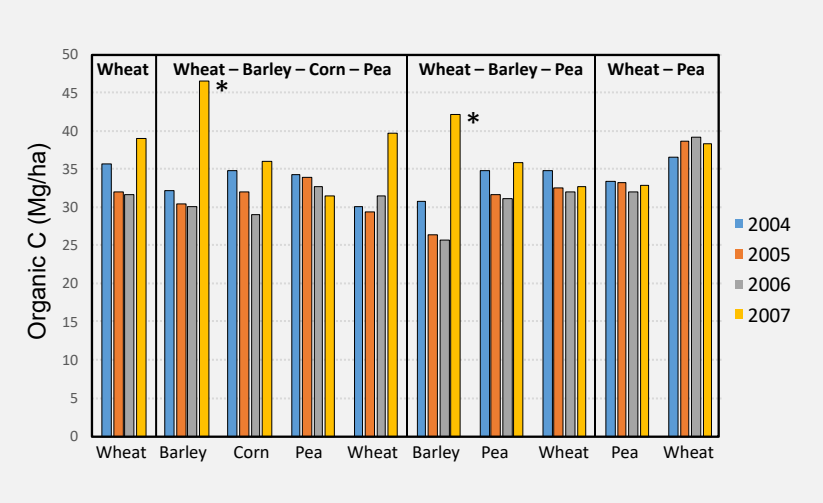
Crop Rotation Experiments

Dryland Cropping System Example

Tests of Effect Slices						
Effect	Treatment	Year	Num DF	Den DF	F Value	Pr > F
Treatment*year	W.W		3	95	0.91	0.4374
Treatment*year	WBCP.B		3	95	5.11	0.0025
Treatment*year	WBCP.C		3	95	0.80	0.4979
Treatment*year	WBCP.P		3	95	0.27	0.8460
Treatment*year	WBCP.W		3	95	1.87	0.1398
Treatment*year	WBP.B		3	95	4.70	0.0042
Treatment*year	WBP.P		3	95	0.88	0.4524
Treatment*year	WBP.W		3	95	0.13	0.9431
Treatment*year	WP.P		3	95	0.07	0.9756
Treatment*year	WP.W		3	95	0.11	0.9554
Treatment*year		2004	9	95	0.33	0.9639
Treatment*year		2005	9	95	0.78	0.6383
Treatment*year		2006	9	95	0.83	0.5860
Treatment*year		2007	9	95	1.94	0.0547

Crop Rotation Experiments

Dryland Cropping System Example



Crop Rotation Experiments

Dryland Cropping System Example

```
estimate 'Wheat' intercept 1 treatment 1;
estimate 'W-B-C-P' intercept 1 treatment 0 .25 .25 .25 .25;
estimate 'W-B-P' intercept 1 treatment 0 0 0 0 0 .333 .333 .334;
estimate 'W-P' intercept 1 treatment 0 0 0 0 0 0 0 0 .5 .5;
estimate 'W vs W-B-C-P' treatment 1 -.25 -.25 -.25 -.25;
estimate 'W vs W-B-P' treatment 1 0 0 0 0 -.333 -.333 -.334;
estimate 'W vs W-P' treatment 1 0 0 0 0 0 0 0 -.5 -.5;
```

Estimates

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
Wheat	34.4515	2.2093	18	15.59	<.0001
W-B-C-P	33.3707	1.0099	18	33.04	<.0001
W-B-P	32.5201	1.1479	18	28.33	<.0001
W-P	35.5028	1.3593	18	26.12	<.0001
W vs W-B-C-P	1.0808	2.4292	18	0.44	0.6617
W vs W-B-P	1.9314	2.4897	18	0.78	0.4480
W vs W-P	-1.0513	2.5940	18	-0.41	0.6900
W-P-B vs W-P	-2.9827	1.7792	18	-1.68	0.1109

Long-Term Experiments

Evaluating Impacts of Agronomic Practices

- Some agronomic practices shift the ecological "equilibrium" of the crop environment
- Their long-term use can cause a transition from one "steady state" to another
- Long-term experiments are designed to assess changes in the crop environment and performance over time
- Examples:
  - Fertility trials
  - Maximum (BMP) yield trials
  - Weed control trials

Gomez and Gomez, 1984.

Long-Term Experiments

Historical Examples (> 100 years)

Name	Location	Estab.	Purpose
Broadbalk Experiment	Rothamsted	1843	Wheat fertility trials
Morrow Plots	Univ. Illinois	1876	Crop rotations
Sanborn Field	Univ. Missouri	1888	Crop rotations, fertility
Magruder Plots	Oklahoma State	1892	Wheat fertility trials
Cullars Rotation	Auburn	1911	Cotton rotation, fertility
Rutherglen Topdressing Experiment	Victoria, Australia	1912	P fertilization of native pasture

Long-Term Experiments

Fertility Trial Example (Gomez and Gomez, 1984)

Treatments:

Replication 3 blocks

Fertility 0-0-0, N-0-0, N-P-0, N-0-K, N-P-K

Year / Season 13 years x 2 seasons/yr = 26 crops

Linear additive model:

$$Y_{ijk} = \mu + R_i + \delta_{(i)} + F_j + RF_{ij} + \omega_{(ij)} + C_k + RC_{ik} + FC_{jk} + RFC_{ijk}$$

Where:

Rf_{ij} = Error a

RFC_{ijk} = Error b

Long-Term Experiments

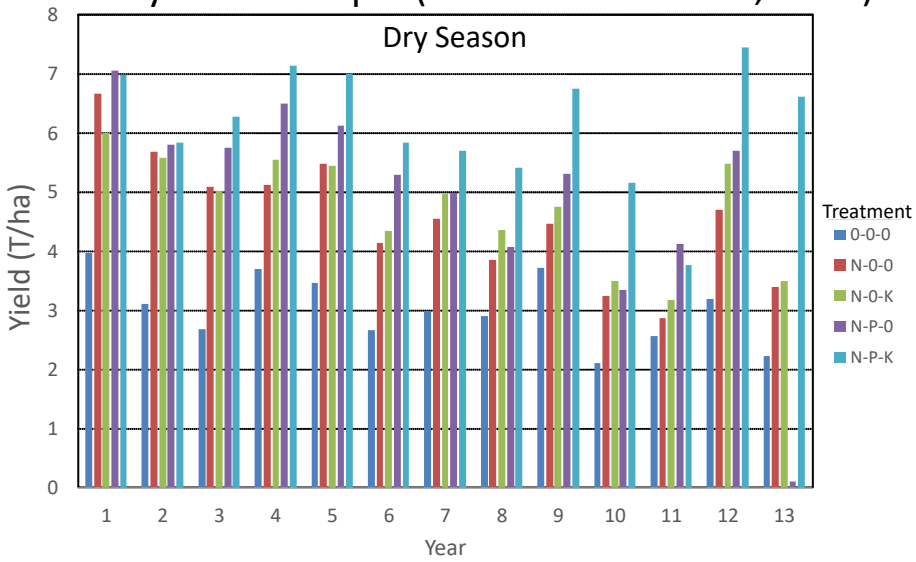
Fertility Trial Example (Gomez and Gomez, 1984)

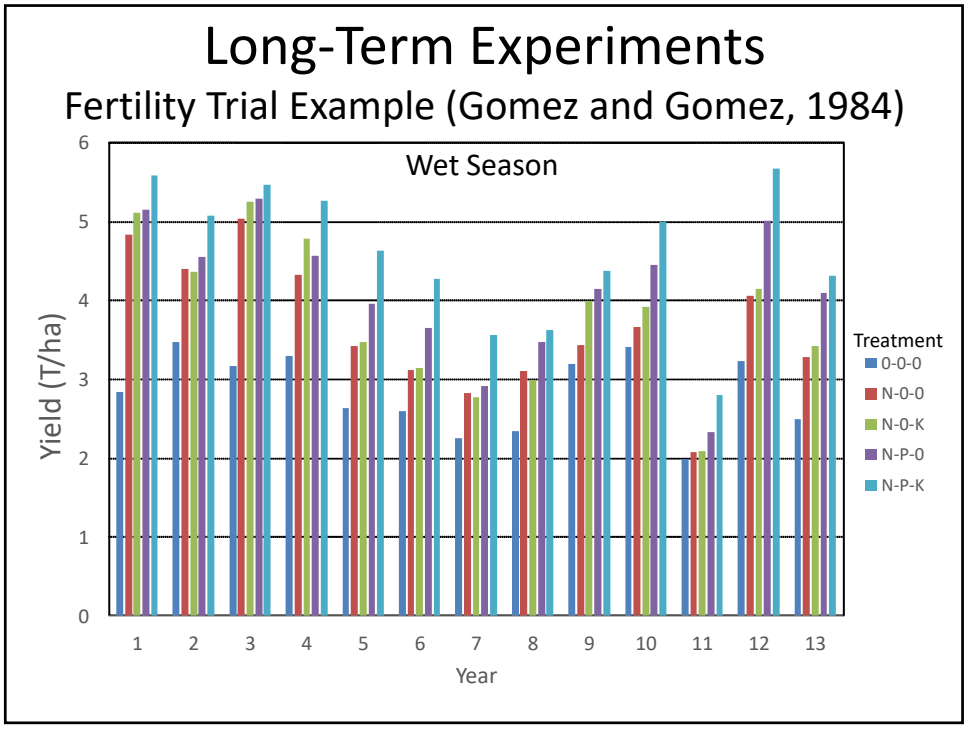
ANOVA:

Source	DF	SS	MS	F
Replication	2	3.4303	1.71515	
Treatment	4	257.6577	64.41441	172.42**
Error(a)	8	2.98876	0.3736	
Crop	25	321.1686	12.84674	108.87**
T x C	100	69.38389	0.69384	5.88**
Error(b)	250	29.49909	0.118	
Total	389	684.1283		

Long-Term Experiments

Fertility Trial Example (Gomez and Gomez, 1984)




Long-Term Experiments
Fertility Trial Example (Gomez and Gomez, 1984)
Wet Season
Yield (T/ha)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
9
10
11
12
13
Year
Treatment
0-0-0
N-0-0
N-0-K
N-P-0
N-P-K