Lattice Designs
Applications in Plant Breeding

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Oregon State University
Presentation Outline

- Why use incomplete block designs?
- Distinguishing features
- Lattice designs – basic plans and field layout
- Statistical analysis
- Cyclic designs and $\alpha$-Lattices
- Meadowfoam breeding example
- Randomization and field plan
- SAS analysis and interpretation
Blocking

**Purpose**
- Reduce experimental error, increase precision
- Compare treatments (genotypes) under more uniform conditions

**The problem**
- In breeding programs, the number of treatments may be large
- As blocks get larger, the conditions within blocks become more heterogeneous
- Other factors may limit the number of experimental units in a block
  - Size of a growth chamber, greenhouse, or available field area
  - Number of samples that can be processed at one time
Incomplete Block Designs

- Plots are grouped into blocks that are not large enough to contain all treatments (genotypes)

- Distinguishing features
  - Number of blocking criteria
  - Balanced or partially balanced
  - Resolvable (or not)
  - Shape (square, rectangular)
  - Process for generating design
Types of Incomplete Block Designs

- **Single blocking criterion**
  - Randomized incomplete blocks

- **Two blocking criteria – based on Latin Squares**
  - Latin Square is a complete block design that requires $N = t^2$. May be impractical for large numbers of treatments.
  - **Row-Column Designs** – either rows or columns or both are incomplete blocks
  - **Youden Squares** – two or more rows omitted from the Latin Square
Balanced Incomplete Block Designs

- Each treatment occurs together in the same block with every other treatment an equal number of times
  - \( t \) = number of treatments
  - \( k \) = number of units per block (block size)
  - \( b \) = total number of blocks in the experiment
  - \( r \) = number of replicates of each treatment
  - \( \lambda \) = number of times that treatments occur together in the same block

- All pairs of treatments are compared with the same level of precision even though differences between blocks may be large

\[
\lambda = \frac{r(k-1)}{t-1}
\]
Balanced Incomplete Block Designs

- For balance, \( r = \lambda(t-1)/(k-1) \)
  - \( t \) = number of treatments
  - \( k \) = number of units per block (block size)
  - \( b \) = total number of blocks in the experiment
  - \( r \) = number of replicates of each treatment
  - \( \lambda \) = number of times that treatments occur together in the same block
  - \( N \) = total number of experimental units

- \( \lambda \) must be an integer; \( N = b*k = r*t \)

- Example: \( t = 10 \) treatments with block size \( k = 4 \)
  - \( r = 6, b = 15, \lambda = 2 \)
  \[ N = b*k = r*t = 6*10 = 60 \]

- In plant breeding, the minimum number of replications required for balance is often too large to be practical
Partially Balanced Incomplete Block Designs

- Different treatment pairs occur in the same blocks an unequal number of times or some treatment pairs never occur together in the same block
  - Mean comparisons have differing levels of precision
    - Greater precision when treatments occur in the same block
  - Statistical analysis more complex

- Common for plant breeding trials due to large number of entries
Resolvable Incomplete Block Designs

- Blocks are grouped so that each group of blocks constitute one complete replication of the treatment
  - “block” = incomplete block = “sub-block”
  - replication = “superblock”
- Trials can be managed in the field on a rep-by-rep basis
- Field operations can be conducted in stages (planting, weeding, data collection, harvest)
- Complete replicates can be lost without losing the whole experiment
- If you have two or more complete replications, you can analyze as an RCBD if the blocking turns out to be ineffective
Lattice Designs are Resolvable

- **Lattice designs** are a well-known type of resolvable incomplete block design

\[ s \times r = b \]

- \( s \) = number of blocks in each complete replication
- \( r \) = number of replicates of each treatment
- \( b \) = total number of blocks in the experiment

- \( t \) = number of treatments
- \( k \) = number of units per block (block size)
- \( b \) = total number of blocks in the experiment
- \( r \) = number of replicates of each treatment
- \( s \) = number of blocks in each complete replication

- \( t \) = 15
- \( k \) = 5
- \( b \) = 6
- \( r \) = 2
- \( s \) = 3
Lattice Designs

Square lattice designs

- Number of treatments must be a perfect square \((t = k^2)\)
- Blocks per replicate \((s)\) and plots per block \((k)\) are equal \((s = k)\) and are the square root of the number of treatments \((t)\)
- For complete balance, number of replicates \((r) = k+1)\)

Rectangular lattice designs

- \(t = s*(s-1)\) and \(k = s-1\)
- Example: 4 x 5 lattice has 4 plots per block, 5 blocks per replicate, and 20 treatments

Alpha lattices

- \(t = s*k\)
- more flexibility in choice of \(s\) and \(k\)
The Basic Plan for a Square Lattice

<table>
<thead>
<tr>
<th>Block</th>
<th>Rep I</th>
<th>Rep II</th>
<th>Rep III</th>
<th>Rep IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3</td>
<td>1 4 7</td>
<td>1 5 9</td>
<td>1 6 8</td>
</tr>
<tr>
<td>2</td>
<td>4 5 6</td>
<td>2 5 8</td>
<td>2 6 7</td>
<td>2 4 9</td>
</tr>
<tr>
<td>3</td>
<td>7 8 9</td>
<td>3 6 9</td>
<td>3 4 8</td>
<td>3 5 7</td>
</tr>
</tbody>
</table>

- **Balance** – each treatment occurs together in the same block with every other treatment an equal number of times
  - Once in this case, so \( \lambda = 1 \)

Basic plans can be found in Cochran and Cox, 1957
Randomization

- Field Arrangement
  - Blocks composed of plots that are as homogeneous as possible

- Randomization of a Basic Plan
  - Randomize order of blocks within replications
  - Randomize the order of treatments within blocks
Example of Randomization of a 3 x 3 Balanced Lattice (t = 9)

1. Assign r random numbers

<table>
<thead>
<tr>
<th>Random</th>
<th>Sequence</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>372</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>217</td>
<td>2</td>
<td>1</td>
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<tr>
<td>963</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>404</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

2. From basic plan

<table>
<thead>
<tr>
<th>Block</th>
<th>Rep I</th>
<th>Rep II</th>
<th>Rep III</th>
<th>Rep IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 2 3</td>
<td>1 4 7</td>
<td>1 5 9</td>
<td>1 6 8</td>
</tr>
<tr>
<td>2</td>
<td>4 5 6</td>
<td>2 5 8</td>
<td>2 6 7</td>
<td>2 4 9</td>
</tr>
<tr>
<td>3</td>
<td>7 8 9</td>
<td>3 6 9</td>
<td>3 4 8</td>
<td>3 5 7</td>
</tr>
</tbody>
</table>

3. Randomize order of replications

<table>
<thead>
<tr>
<th>Block</th>
<th>Rep I</th>
<th>Rep II</th>
<th>Rep III</th>
<th>Rep IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 4 7</td>
<td>1 2 3</td>
<td>1 6 8</td>
<td>1 5 9</td>
</tr>
<tr>
<td>2</td>
<td>2 5 8</td>
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<tr>
<td>3</td>
<td>3 6 9</td>
<td>7 8 9</td>
<td>3 5 7</td>
<td>3 4 8</td>
</tr>
</tbody>
</table>

4. Randomize blocks within reps

<table>
<thead>
<tr>
<th>Rep</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
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<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

5. Resulting new plan

<table>
<thead>
<tr>
<th>Block</th>
<th>Rep I</th>
<th>Rep II</th>
<th>Rep III</th>
<th>Rep IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 6 9</td>
<td>4 5 6</td>
<td>3 5 7</td>
<td>1 5 9</td>
</tr>
<tr>
<td>2</td>
<td>2 5 8</td>
<td>1 2 3</td>
<td>1 6 8</td>
<td>3 4 8</td>
</tr>
<tr>
<td>3</td>
<td>1 4 7</td>
<td>7 8 9</td>
<td>2 4 9</td>
<td>2 6 7</td>
</tr>
</tbody>
</table>
Partially Balanced Lattices

- **Simple Lattices**
  - Two replications — use first two from basic plan
  - 3x3 and 4x4 are no more precise than RCBD because error df is too small

- **Triple Lattices**
  - Three replications — use first three from basic plan
  - Possible for all squares from 3x3 to 13x13

- **Quadruple Lattices**
  - Four replications — use first four from basic plan
  - Do not exist for 6x6 and 10x10
    - can repeat simple lattice, but analysis is different
Linear Model for Lattice Design

- Example is for a single blocking factor

\[ Y_{ijl} = \mu + \tau_i + \gamma_j + \rho_{l(j)} + \varepsilon_{ijl} \]

- Treatment effect
  \( i = 1, 2, \ldots, t \)

- Replicate effect
  \( j = 1, 2, \ldots, r \)

- Block within replicate effect
  \( l = 1, 2, \ldots, s \)

- Random error
ANOVA

- Form of the analysis is the same for simple, triple and quadruple lattices
- Two error terms are computed
  - $E_b$ — Error for block = $SSB/r(k-1)$
  - $E_e$ — Experimental error = $SSE/((k-1)(rk-k-1))$

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$rk^2-1$</td>
<td>$SSTot$</td>
<td></td>
</tr>
<tr>
<td>Replications</td>
<td>$r-1$</td>
<td>$SSR$</td>
<td></td>
</tr>
<tr>
<td>Treatments (unadj)</td>
<td>$k^2-1$</td>
<td>$SST$</td>
<td></td>
</tr>
<tr>
<td>Block in rep (adj)</td>
<td>$r(k-1)$</td>
<td>$SSB$</td>
<td>$E_b$</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>$(k-1)(rk-k-1)$</td>
<td>$SSE$</td>
<td>$E_e$</td>
</tr>
</tbody>
</table>
Computing Sums of Squares

- **SSTOT** = \( \sum Y_{ijl}^2 - \left( G^2 / rk^2 \right) \)
  - G is the grand sum of all plots in the experiment

- **SSR** = \( (1 / k^2) \sum R_j^2 - \left( G^2 / rk^2 \right) \)
  - \( R_j \) is the sum of all plots in the \( j^{th} \) replication

- **SSB** = \( \left( 1 / kr(r - 1) \right) \sum C_{jl}^2 - \left( 1 / k^2 r(r - 1) \right) \sum C_j^2 \) (adjusted)
  - \( C_{jl} \) = sum over all replications of all treatments in the \( l^{th} \) block of the \( j^{th} \) replication minus \( rB_{jl} \)
  - \( B_{jl} \) = sum of the \( k \) plots in the \( l^{th} \) block of the \( j^{th} \) replication
  - \( C_j \) = sum of all \( C_{jl} \) in the \( j^{th} \) replication

- **SST** = \( (1 / r) \sum T_i^2 - \left( G^2 / rk^2 \right) \) (unadjusted)
  - \( T_i \) = sum of the \( i^{th} \) treatment across replications

- **SSE** = **SSTot** – **SSR** – **SSB** – **SST**
Adjustment factor

- Compare $E_b$ with $E_e$: If $E_b \leq E_e$
  - Adjustment of treatment means will have no effect
  - Analyze as if it were an RCBD using replications as blocks

- If $E_b > E_e$ then compute an adjustment (weighting) factor $A$
  - $A = (E_b - E_e) / (k(r - 1)E_b)$
  - used to compute adjusted treatment means

$$
\bar{Y}_{i(adj)} = \left( T_i + \sum AC_{jl} \right) / r
$$

For all blocks in which the $i^{th}$ treatment occurs
Testing Treatment Differences

To test significance among adjusted treatment means, compute an adjusted mean square

- \( \text{SSB}_u = (1/k) \sum B_{jl}^2 - (G^2 / rk^2) - \text{SSR} \)
- \( \text{SST}_{adj} = \text{SST} - A(k-1)[((r \text{SSB}_u)/(r-1)(1+kA)) - \text{SSB}] \)
- \( \text{MST}_{adj} = \text{SST}_{adj} / (k^2 - 1) \)

Finally, compute the F statistic for testing the differences among the adjusted treatment means

- \( F = \text{MST}_{adj} / \text{E}_e \)
  
  with \( k^2 - 1 \) and \((k-1)(rk-k-1)\) degrees of freedom
Standard Errors

- Compute the effective error mean square
  - \( E_e' = \left[ 1 + \left( \frac{rkA}{(k+1)} \right) \right] E_e \)

- SE of adjusted treatment mean
  - \( \sqrt{\frac{E_e'}{r}} \)

- SE of difference between adjusted means in same block
  - \( \sqrt{\left( \frac{2E_e}{r} \right) \left( 1 + \left( \frac{r-1}{A} \right) \right)} \)

- SE of difference between adjusted means in different blocks
  - \( \sqrt{\frac{2E_e}{r} \left( 1 + \frac{rA}{A} \right)} \)

- For larger lattices (\( k > 4 \)) it is sufficient to use
  - \( \sqrt{\frac{2E_e'}{r}} \)
Relative Efficiency

- Estimate the error mean square of an RCBD
  \[ E_{RCBD} = \frac{SSB+SSE}{(k^2-1)(r-1)} \]

- Then the relative efficiency of the lattice is
  \[ RE = \frac{E_{RCBD}}{E_e'} \]
Numerical Example - Simple Lattice

Rep I

<table>
<thead>
<tr>
<th>Block</th>
<th>Barley Yield kg/plot</th>
<th>B_jl</th>
<th>C_jl</th>
<th>Adj</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(19) (16) (18) (17) (20)</td>
<td>18.2</td>
<td>13.0</td>
<td>9.5</td>
</tr>
<tr>
<td>2</td>
<td>(12) (13) (15) (14) (11)</td>
<td>13.3</td>
<td>11.4</td>
<td>14.2</td>
</tr>
<tr>
<td>3</td>
<td>(1) (2) (3) (4) (5)</td>
<td>15.0</td>
<td>12.4</td>
<td>17.3</td>
</tr>
<tr>
<td>4</td>
<td>(22) (24) (21) (25) (23)</td>
<td>7.0</td>
<td>5.9</td>
<td>14.1</td>
</tr>
<tr>
<td>5</td>
<td>(9) (7) (10) (8) (6)</td>
<td>11.9</td>
<td>15.2</td>
<td>17.2</td>
</tr>
</tbody>
</table>

Selection number in ()

Example from Petersen, R.G. 1994. Agricultural Field Experiments
## Numerical Example - Simple Lattice

### Rep 2

<table>
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<tr>
<th>Block</th>
<th>Barley Yield kg/plot</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B&lt;sub&gt;jl&lt;/sub&gt;</td>
<td>C&lt;sub&gt;jl&lt;/sub&gt;</td>
<td>Adj</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(23) (18) (3) (8) (13)</td>
<td>7.7</td>
<td>15.2</td>
<td>19.1</td>
<td>15.5</td>
<td>14.7</td>
</tr>
<tr>
<td>2</td>
<td>(5) (20) (10) (15) (25)</td>
<td>15.8</td>
<td>18.0</td>
<td>18.8</td>
<td>14.4</td>
<td>20.0</td>
</tr>
<tr>
<td>3</td>
<td>(22) (12) (2) (17) (7)</td>
<td>10.2</td>
<td>11.5</td>
<td>17.0</td>
<td>11.0</td>
<td>15.3</td>
</tr>
<tr>
<td>4</td>
<td>(14) (24) (9) (4) (19)</td>
<td>10.9</td>
<td>4.7</td>
<td>10.9</td>
<td>16.6</td>
<td>9.8</td>
</tr>
<tr>
<td>5</td>
<td>(6) (16) (11) (21) (1)</td>
<td>20.0</td>
<td>21.1</td>
<td>16.9</td>
<td>10.9</td>
<td>15.0</td>
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</table>

<table>
<thead>
<tr>
<th>Selection number in (</th>
<th>Sum</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>361.0</td>
<td>-30.5</td>
<td>-2.67</td>
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<td>Grand Sum</td>
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<td>691.5</td>
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Initial ANOVA

<table>
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<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>49</td>
<td>805.42</td>
<td></td>
</tr>
<tr>
<td>Replication</td>
<td>1</td>
<td>18.60</td>
<td></td>
</tr>
<tr>
<td>Selection (unadj)</td>
<td>24</td>
<td>621.82</td>
<td></td>
</tr>
<tr>
<td>Block in rep (adj)</td>
<td>8</td>
<td>77.59</td>
<td>9.70=E_b</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>16</td>
<td>87.41</td>
<td>5.46=E_e</td>
</tr>
</tbody>
</table>

E_b > E_e so we compute the adjustment factor, A

\[
A = \frac{(E_b - E_e)}{(k(r-1)E_b)} = \frac{(9.70 - 5.46)}{(5)(1)(9.70)} = 0.0874
\]

Adjustment of mean for Entry 1

\[
Y_{1(adj)} = \left( T_1 + \sum AC_{ji} \right) / r = \left[ 30 + (0.0874 \times 5.3) + (0.0874 \times 1.35) \right] / 2 = 14.69
\]
Intrablock ANOVA of Adjusted Means

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>49</td>
<td>805.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replication</td>
<td>1</td>
<td>18.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selection (adj)</td>
<td>24</td>
<td>502.39</td>
<td>20.93</td>
<td>3.83**</td>
</tr>
<tr>
<td>Block in rep (unadj)</td>
<td>8</td>
<td>252.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intrablock error</td>
<td>16</td>
<td>87.41</td>
<td>5.46</td>
<td></td>
</tr>
</tbody>
</table>

- It may be better to use the effective error in the denominator of the F test
  - \( E_e' = (1+(rkA)/(k+1))E_e = (1+(2*5*0.0874)/6)*5.46 = 6.26 \)
  - \( F = 20.93/6.26 = 3.34** \)

- See the supplemental Excel spreadsheet for more details
Relative Efficiency

- How does the precision of the Lattice compare to that of a randomized complete block design?
  
  First compute MSE for the RCBD as:
  
  \[ E_{RCBD} = \frac{(SSB+SSE)}{(k^2 - 1)(r -1)} = \frac{(77.59 + 87.41)}{(24)(1)} = 6.88 \]
  
  Then % relative efficiency =

  \[ \left( \frac{E_{RCBD}}{E_e} \right) \times 100 = \left( \frac{6.88}{6.26} \right) \times 100 = 110.0\% \]

  There is a 10% gain in efficiency from using the lattice.
Cyclic Designs

- Incomplete Block Designs discussed so far
  - Require extensive tables of design plans
  - Need to avoid mistakes when assigning treatments to experimental units and during field operations

- Cyclic designs are a type of incomplete block design
  - Relatively easy to construct and implement
  - Generated from an initial block
  - Example: 6 treatments, block size = 3
  - Add one to each treatment label for each additional block
  - Modulo t=6

<table>
<thead>
<tr>
<th>Block</th>
<th>Treatment Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0, 1, 3</td>
</tr>
<tr>
<td>2</td>
<td>1, 2, 4</td>
</tr>
<tr>
<td>3</td>
<td>2, 3, 5</td>
</tr>
<tr>
<td>4</td>
<td>3, 4, 0</td>
</tr>
<tr>
<td>5</td>
<td>4, 5, 1</td>
</tr>
<tr>
<td>6</td>
<td>5, 0, 2</td>
</tr>
</tbody>
</table>

Good reference: Kuehl, 2000, Chapt. 10
Alpha designs

- Patterson and Williams (1976) described a new way to construct cyclic, resolvable incomplete block designs
- $\alpha$-designs are available for many $(r,k,s)$ combinations
  - $r$ is the number of complete replicates
  - $k$ is the block size
  - $s$ is the number of blocks per replicate
  - Number of treatments $t = sk$
- Efficient $\alpha$-designs exist for some combinations for which conventional lattices do not exist
- Can accommodate unequal block sizes
- Two types: $\alpha(0, 1)$ and $\alpha(0, 1, 2)$
  - Indicates values of $\lambda$ that occur in the trial (2 or 3 associate classes)
Alpha Designs - Software

- **Gendex**  [http://designcomputing.net/gendex/alpha/](http://designcomputing.net/gendex/alpha/)
  - Can generate **optimal** or **near-optimal** α-designs
  - Up to 10,000 entries
  - Evaluation/academic copy is free and can be downloaded
  - Cost for commercial perpetual license is $299

- **CycDesigN**

- **Agrobase**

- **R agricolae package**
  - design.alpha, design.lattice, design.cyclic, design.bib

- **SAS PROC PLAN**
  - some code required
  - [http://www.stat.ncsu.edu/people/dickey/courses/st711/Demos/](http://www.stat.ncsu.edu/people/dickey/courses/st711/Demos/)
Efficiency Factors for Lattice Designs

- **Balanced lattice**
  \[ E = \frac{(k + 1)(r - 1)}{r(k + 2) - (k + 1)} \]

- **Simple lattice**
  \[ E = \frac{k + 1}{k + 3} \]

- **Triple lattice**
  \[ E = \frac{2k + 2}{2k + 5} \]

- **Alpha lattice**
  (upper bound)
  \[ E = \frac{(t-1)(r-1)}{(t-1)(r-1) + r(s-1)} \]

- Use as large a block size as possible while maintaining homogeneity of plots within blocks.

- **t** = # treatments, **k** = block size, **s** = # blocks/rep, **r** = # complete reps
Analysis of Lattice Experiments

- **SAS**
  - PROC MIXED, PROC LATTICE
  - PROC VARCOMP (random genotypes)
  - PROC GLIMMIX (non-normal)

- **ASREML**

- **GENSTAT**

- **R**
  - stats, lme4 packages

- **Agrobase**
  - [www.agronomix.com/](http://www.agronomix.com/)
Meadowfoam (*Limnanthes alba*)

- Native to vernal pools in the PNW
- First produced as a crop in 1980
- Seed oil with novel long-chain fatty acids
  - light-colored and odor free
  - exceptional oxidative stability
- Used in personal care products
- Potential uses
  - fuel additive
  - vehicle lubricants
  - pharmaceutical products
GJ Pool Progeny Trial, 2012 (α-Lattice)

- Plot size 4 ft x 12 ft (planted 2000 seeds/plot)
- Average seed yield 1612 kg/ha
Autoferitile Progeny Trial, 2013

- 132 entries
- 127 TC + 5 checks
- 11 x 12 α-lattice
- 2 replications
- 1 location
- 4 ft x 10 ft plots
- 1450 seeds/plot

Average seed yield 879 kg/ha
Meadowfoam Reproduction

- Winter annual, diploid

- Factors that promote outcrossing:
  - Protandrous
  - Heterostylos
  - Many native pollinators
  - Inbreeding depression in *L. alba* ssp *alba*

- Potential for selfing
  - Perfect flowers
  - Self-compatible
  - Flowers close at night

Figure 2 — Sequential reproductive development of a Mermaid meadowfoam flower:

A. Flower opening with initial pollen availability (dehiscence) and receptive stigmas
B. Maximum pollen shed with non-receptive stigmas
C. Maximum stigmatic receptivity with reduced pollen availability
Autoferitile Pool

- Derived from crosses between
  - Outcrossing *L. alba* ssp. *alba* populations
  - Self-pollinating lines from *L. alba* ssp. *versicolor*

- Inbreeding depression??

- Development of progeny for evaluation
  - Selfed plants in the greenhouse for two generations, without pollinators
  - Selected for autofertility (seed number)
  - Planted *S2* families in an isolated nursery with honeybees to produce testcross progeny
S₂ Families in Isolated Nursery

- Planted 5 seeds per family in short rows
- 2 replicates
- Randomized blocks
- Honeybee pollinators
Best alpha design for $v=132$, $r=2$, $k=11$, and $s=12$.  

<table>
<thead>
<tr>
<th>Plan (blocks are rows):</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>84</td>
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<tr>
<td>10</td>
</tr>
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<td>131</td>
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<td>123</td>
</tr>
<tr>
<td>122</td>
</tr>
<tr>
<td>75</td>
</tr>
</tbody>
</table>
Field Map for the Autofertile Trial (Rep 1)

Block 1
Data Set – Variables Included

- Plant height cm
- 1000-seed weight (TSW)
- Seed oil content (%)
- Seed yield kg/ha
SAS Data Input

ods html close; ods html;
data AF2013;
Input PLOT REP BLOCK ENTRY NAME$ Height TSW Oil Yield;
Oilyld=yield*oil/100;
datalines;
1001 1 1 82 179-53-2 22.5 9.48 26.16 782
1002 1 1 83 179-56-1 22.5 9.38 27.42 832
1003 1 1 97 179-83-1 23.5 8.56 24.25 944
1004 1 1 117 188-14-1 19.5 7.90 28.11 721
.;
.
. ;
2129 2 24 89 179-63-1 24.0 10.10 26.68 858
2130 2 24 74 179-38-1 22.5 9.35 28.40 631
2131 2 24 53 179-4-2 20.5 9.51 25.76 1127
2132 2 24 127 188-133-2 22.5 9.62 25.37 721 ;
Mixed Model Analysis of Yield

PROC MIXED;
TITLE 'Lattice analysis of yield: PROC MIXED, entries fixed';
CLASS REP BLOCK ENTRY;
MODEL Yield = ENTRY;
RANDOM REP BLOCK(REP) /solution;
ods output solutionr=syield;
/*test for entries that differ from Ross*/
LSMEANS entry/pdiff=CONTROL('128');
ods output lsmeans=Yieldadj diffs=Ylddiff;
RUN;

Use export wizard to export
- syield
- Yieldadj
- Ylddiff
Analysis of Yield (fixed entries)

The Mixed Procedure
Covariance Parameter Estimates

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<thead>
<tr>
<th>Cov Parm</th>
<th>Estimate</th>
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<tbody>
<tr>
<td>REP</td>
<td>2435.58</td>
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<tr>
<td>BLOCK(REP)</td>
<td>9900.50</td>
</tr>
<tr>
<td>Residual</td>
<td>12657</td>
</tr>
</tbody>
</table>

Fit Statistics

-2 Res Log Likelihood | 1753.2
AIC (smaller is better) | 1759.2
AICC (smaller is better) | 1759.3
BIC (smaller is better) | 1755.2

Type 3 Tests of Fixed Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Num</th>
<th>Den</th>
<th>F Value</th>
<th>Pr &gt; F</th>
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<tbody>
<tr>
<td>Entry</td>
<td>131</td>
<td>109</td>
<td>6.17</td>
<td>&lt;.0001</td>
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</table>
### Analysis of Yield – Random Effects

<table>
<thead>
<tr>
<th>Cov Parm</th>
<th>Height</th>
<th>TSW</th>
<th>Oil</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP</td>
<td>0.191</td>
<td>0.0369</td>
<td>0.4252</td>
<td>2435.6</td>
</tr>
<tr>
<td>BLOCK(REP)</td>
<td>1.568</td>
<td>0</td>
<td>0.1696</td>
<td>9900.5</td>
</tr>
<tr>
<td>Residual</td>
<td>2.238</td>
<td>0.1972</td>
<td>1.0360</td>
<td>12657.0</td>
</tr>
</tbody>
</table>
Conclusion

- α-Lattice Designs?
- Yes!
- You have nothing to lose
- They are most helpful when you need them the most
Lattice Design References

Acknowledgements

- **Funding**
  - OMG Meadowfoam Oil Seed Growers Cooperative
  - Paul C. Berger Professorship Endowment
  - Crop and Soil Science Department, OSU

- **Meadowfoam Staff**
  - Gary Sandstrom
  - Ann Corey
  - Student workers

- **Lattice Design Examples**
  - Matthais Frisch
  - Roger Petersen
  - Nan Scott