Rate of Forage Yield Breeding Gains in a Red Clover Breeding Program

Heathcliffe Riday
Background

- Occasional breeding gain papers published
  - Usually compare varieties by release year

- Difficult studies to conduct

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### Table 2

<table>
<thead>
<tr>
<th>Trait</th>
<th>Benchmark variety</th>
<th>Improved varieties</th>
<th>Genetic gain (% yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM yield†</td>
<td>G. Turoa</td>
<td>G. Hamua, Pawera</td>
<td>0.43</td>
</tr>
<tr>
<td>DM yield†</td>
<td>G. Hamua</td>
<td>G. Colenso</td>
<td>0.21</td>
</tr>
<tr>
<td>DM yield†</td>
<td>G. Pawera (4x)</td>
<td>G27 (4x)</td>
<td>1.39</td>
</tr>
<tr>
<td>1st post-seeding year DM yield‡</td>
<td>Lakeland</td>
<td>Arlingtonb, Marathonc</td>
<td>0.41</td>
</tr>
<tr>
<td>2nd post-seeding year DM yield‡</td>
<td>Lakeland</td>
<td>Arlington, Marathon</td>
<td>0.55</td>
</tr>
<tr>
<td>3rd post-seeding year DM yield‡</td>
<td>Lakeland</td>
<td>Arlington, Marathon</td>
<td>0.95</td>
</tr>
<tr>
<td>Trial DM yield‡</td>
<td>Lakeland</td>
<td>Arlington, Marathon</td>
<td>0.60</td>
</tr>
<tr>
<td>Establishment survival§</td>
<td>Lakeland</td>
<td>Arlington, Marathon, C328d</td>
<td>0.94</td>
</tr>
<tr>
<td>12-month survival§</td>
<td>Lakeland</td>
<td>Arlington, Marathon, C328</td>
<td>1.94</td>
</tr>
<tr>
<td>24-month survival§</td>
<td>Lakeland</td>
<td>Arlington, Marathon, C328</td>
<td>1.43</td>
</tr>
<tr>
<td>36-month survival§</td>
<td>Lakeland</td>
<td>Arlington, Marathon, C328</td>
<td>2.78</td>
</tr>
<tr>
<td>48-month survival§</td>
<td>Lakeland</td>
<td>Arlington, Marathon, C328</td>
<td>1.32</td>
</tr>
</tbody>
</table>

† Woodfield and Brummer (2001), ‡ Data from Six trials planted 1986 to 1991 in Wisconsin, USA. (Smith et al. 1987-1994; Riday and Krohn 2010a), § Data from 1 Rotational Grazed red clover – tall fescue mixture trial established 2004 in Wisconsin, USA (Riday et al. 2007). ¶ Unpublished results from (Riday et al. 2007), a – released 1953 (Hollowell 1961); b – released 1973 (Smith et al. 1973); c – released 1987 (Smith et al. 1994); and d – unreleased experimental first tested in 1992 (Smith 2000).
• Visual score for biomass plant\(^{-1}\)
  – 3 to 5 time per year
  – 4 summers and 3 winters
  – 12 to 18 total observations per plant

• Common check cultivar and halfsib families statistically bind nurseries together across locations and years

• Each nursery x scoring date “cohort” is standardized = 9 x (vig. score/99\(^{th}\) percentile obs.)
  – Observed dead plants are given a zero vigor score

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Fig. 1 Individual normalized plant fresh weights (standard deviations) plotted against the average of two normalized biomass yield scores (standard deviations) with fitted exponential function (fresh weight = 0.3784e\(^{0.475 \times \text{score}}\) + 1.923) (pseudo-\(R^2 = 0.79\))

(Riday, 2009)
Selection Program

Breeding Population

Intermating → Evaluation → Selection
A more complex perspective

Breeding Population

Intermating → Evaluation

Selection
A more complex perspective

Time

- Individual plant observations database

- Family means
  - "Genotypic Selection"

- Grow individuals from remnant seed of best families and intermate
  - "Genotypic Selection"

- Experimental variety testing and initial seed increase

- Experimental variety testing and initial seed increase

- Interminate groups of selected plants

- Large scale seed increase

- "Phenotypic Selection"
Data 2006-2015

- 694,134 repeated individual plant vigor observations
- Taken on 66,649 unique plants
  - Of these 9,065 paternity identified using DNA markers
- From 1,824 entries (halfsib families, populations, or varieties)
  - With halfsib families derived from 104 polycrosses
  - Minimum of 40 plants entry$^{-1}$ to make selection decision
- Evaluated across 61 nurseries

Information used for Genotypic Selection
Red Clover Breeding Progress

- Performance of Top 10% of Dairy Forage Research Center Red Clover Breeding Lines

4.0% Performance Gain Per Year

- % Performance Relative to Marathon Red Clover

- Halfsib Family Creation Year


- Starfire II
- Freedom!MR
- Marathon
- Cinnamon Plus
- Southern Belle
Predicting Sward Performance from Visual Space-Plant Evaluations

Wisconsin Sward Variety Trial Performance % of Marathon

Space-Planted Breeding Nursery Performance % of Marathon

Varieties:
- Cinnamon Plus
- DFRC2
- DFRC3
- DFRC4
- DFRC5
- DFRC6
- DFRC7
- DFRC8
- DFRC9
- DFRC10
- Freedom!MR
- Starfire II
- Marathon
- Southern Belle
Predicting Sward Performance from Visual Space-Plant Evaluations

\[ y = 0.244x + 78.1 \]

\[ R^2 = 0.254; P < 0.05 \]
Predicting Sward Performance from Visual Space-Plant Evaluations

\[
y = 0.244x + 78.1
\]

\[R^2 = 0.254; P < 0.05\]

Estimated 1.0% Sward Performance Gain Per Year

2014 Top 10% Mean

Space-Planted Breeding Nursery Performance % of Marathon vs. Wisconsin Sward Variety Trial Performance % of Marathon
Genotypic vs. Phenotypic Selection

Proportion

<table>
<thead>
<tr>
<th>Year</th>
<th>Genotypic Selection derived halfsib families</th>
<th>Phenotypic Selection derived halfsib families</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011*</td>
<td>0.29</td>
<td>0.71</td>
</tr>
<tr>
<td>2012</td>
<td>0.29</td>
<td>0.71</td>
</tr>
<tr>
<td>2013</td>
<td>0.31</td>
<td>0.69</td>
</tr>
<tr>
<td>2014</td>
<td>0.35</td>
<td>0.65</td>
</tr>
</tbody>
</table>

* Year halfsib family was created
Genotypic vs. Phenotypic Selection

2011*: 0.71 (All) 0.29 (Top 10%)
2012*: 0.71 (All) 0.29 (Top 10%)
2013 NS: 0.69 (All) 0.31 (Top 10%)
2014*: 0.65 (All) 0.35 (Top 10%)

Proportion

χ²-test significant at \( P < 0.05 \)
## Genotypic vs. Phenotypic Selection

<table>
<thead>
<tr>
<th>Year</th>
<th>Genotypic Selection derived halfsib families in Top 10% of tested families</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>6.19</td>
</tr>
<tr>
<td>2012</td>
<td>4.88</td>
</tr>
<tr>
<td>2013</td>
<td>0.73</td>
</tr>
<tr>
<td>2014</td>
<td>5.63</td>
</tr>
<tr>
<td>Mean</td>
<td>3.34*</td>
</tr>
</tbody>
</table>

x-times more genotypic selection derived halfsib families than equal expectation

* geometric mean; different from 1 at $P = 0.098$
Rate of Obsolescence

• Since 2006 ~ 180 halfsib families added to the evaluation program each year
  – By 2016 ~1,800 halfsib families to select among

<table>
<thead>
<tr>
<th>Genotypic Selection</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of halfsib families selected</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Average age of halfsib family selected</td>
<td>5.5</td>
<td>4.8</td>
<td>5.6</td>
<td>5.0</td>
<td>4.4</td>
<td>3.4</td>
<td>4.8</td>
</tr>
</tbody>
</table>

• “Effective” genotypic selection intensity ~ 6/(4.8*18) ≈ 2%
• Phenotypic selection intensity ~ 5% to 8%
Red Clover Breeding Progress

- Performance of Top 10% of Dairy Forage Research Center Red Clover Breeding Lines

% Performance Relative to Marathon Red

4.0% Performance Gain Per Year

Start-up Lag Time

- Starfire II
- Freedom!MR
- Marathon
- Cinnamon Plus
- Southern Belle

Halvesib Family Creation Year
Conclusions

• Breeding works

• 4% estimated vigor breeding gains year\(^{-1}\)
  – 1% estimated sward biomass yield gain

• Genotypic selection program is 3.3 times more effective than the phenotypic selection program

• Halfsib families currently have an average 4.8 year utility in the program

• Apparent genetic gain lag time at the start of the program
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