HERITABILITY OF RESILIENCE TO DEFICIT IRRIGATION IN TALL FESCUE

Forage and Range Research Laboratory

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What is ‘Resilience’?

- Resilience is perhaps one of the predominate ‘Buzz’ words of the decade – often associated with climate change
  - Appeared 22 times in USDA-ARS Forage and Range Research 5-year plan (2019-2024)

- “Resilience in forage and grazingland systems is difficult to quantify.” Tracy et al., 2018. Crop Science.

- “Resilience is the ability to withstand a short-term crisis, perturbation, or shock, like drought . . .” Picasso et al., 2019. Crop Science.

- In order to study resilience, an operational measure of resilience is needed. Picasso et al., 2019. Crop Science.
Proposed **Productivity**, **Stability**, and **Resilience** variable operational definitions.

- e.g., a metric that would enable examining differences in resilience among alfalfa cultivars

Based upon identifying a crisis event/year/environment from forage yield trials/ datasets.

- **Is Resilience** a heritable trait?
- Can we breed for improved resilience per se in a forage species?
- Could we use a line-source sprinkler experiment to simulate a ‘crisis’ drought environment?
Materials and Methods

Studied these questions using a line-source sprinkler irrigation – tall fescue forage mass data set.

• Plant Materials and Plots:
  – 30 Tall fescue (*Schendonorus arundinaceus* [Schreb.] Dumort, nom. Cons.) half-sib families (HSF).
    • HSF developed by 2-cycles of selection for soft leaves and vegetative vigor in non-competitive spaced-plant nurseries.
  – Sward plots were established in a line-source sprinkler experiment.
    • Irrigation gradient established such that there were five 2-m ranges with the range closest to the sprinkler received 110% of evapotranspiration (ET) replacement and each successive distal range experiencing greater deficit irrigation.
      • i.e., five ranges that received 110, 88, 62, 43, and 20% growing season ET replacement, respectively.
  – Plots were mechanically harvested five times per growing season, and yearly forage mass determined for three consecutive years (2001, 2002, 2003).
Line-source Sprinkler Irrigation: Linear water gradient

WL5 (20% ET replacement) receives ~ 0 supplemental irrigation.
Line-source Irrigation: Seasonal growth gradient
Materials and Methods: Harvesting
“Variable Operational Definitions”:

- **Productivity, Stability, and Resilience** estimated for each HSF.
  - Considering each irrigation level a different environment.
  - Considering the lowest irrigation level (20% ET replacement) as the crisis environment.
  - Calculated within years and reps.

\[
P_{jl} = \frac{\sum_{i}^{n-1} Y_{ijl}}{n-1}
\]

\[
S_{jl} = \frac{P_{jl}}{SE(P_{jl})}
\]

\[
R_{jl} = \frac{Y_{cjl}}{P_{jl}}
\]

- Where \( P_{jl} \) is **Productivity** and \( Y_{ijl} \) is yield of HSF \( j \) in replication \( i \) for irrigation environment \( I \); (i.e., mean forage mass over non-crisis environments).

- Where \( S_{jl} \) is **Stability** and \( SE(P_{jl}) \) is the standard error of the productivity.

- Where \( R_{jl} \) is **Resilience** and \( Y_{cjl} \) is yield of HSF \( j \) in the crisis irrigation environment \( I \); (i.e., ratio of crisis to non-crisis productivity).
Materials and Methods: Genetic correlations

• Genetic Analysis:
  – Narrow-sense heritabilities ($h^2$) estimated for forage Productivity, Stability, and Resilience and at each irrigation level; and
  – Genetic correlations ($r_G$) estimated between Productivity, Stability, and Resilience and each irrigation level.

  • Genetic correlation is based upon resemblance between relatives (e.g. variance between HSF = $\frac{1}{4}$ genetic variance).
  • “The genetic correlation expresses the extent to which two measurements reflect what is genetically the same character.” (Falconer, 1989)
  • Can be extended to the genetic correlation between ‘selection environments’.
  • $r_G = \frac{\text{cov}_{xy}}{\sqrt{\text{var}_x \text{var}_y}}$
  • “... the magnitude and even the sign of the genetic correlation cannot be determined from phenotypic correlation alone” because $r_p$ includes environmental correlation (Falconer, 1989).
Materials and Methods: Correlated response

• Genetic Analysis continued:
  – Predicted response of direct selection, and correlated response and relative efficiency (RE) of indirect selection estimated for 1-cycle of selection on a HSF mean basis.
    • Response: \( R_x = k_p \ h_x \ \sigma_{G(x)} \)
    • Correlated Response: \( CR_x = k_p \ h_x \ r_G \ \sigma_{G(y)} \)
    • RE: \( CR_x/R_x = r_G \ h_y/h_x \)
    • If RE > 1.0 then indirect selection more efficient.
    • Assumed a selection intensity of 15% such that the standardized selection differential (\( k_p \)) = 1.446.

Mike Casler: “Progress = (intensity X accuracy X variation) ÷ time”

So we are predicting progress from breeding for increased Resilience:

\[ = (\text{selection intensity} \times \text{genetic correlation} \times \text{heritability}) \div 1\text{-cycle of selection} \]
RESULTS & DISCUSSION
### Results: Forage mass

Table 1. Average forage mass of 30 tall fescue half-sib families (HSF) growing in varying deficit irrigation environments.

<table>
<thead>
<tr>
<th>Irrigation Level</th>
<th>ET Replacement</th>
<th>Forage Mass</th>
<th>P-value (among HSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL 1</td>
<td>110</td>
<td>12.9</td>
<td>0.0441</td>
</tr>
<tr>
<td>WL 2</td>
<td>88</td>
<td>11.7</td>
<td>0.0249</td>
</tr>
<tr>
<td>WL 3</td>
<td>62</td>
<td>8.8</td>
<td>0.1093</td>
</tr>
<tr>
<td>WL 4</td>
<td>43</td>
<td>6.7</td>
<td>0.0283</td>
</tr>
<tr>
<td>WL 5</td>
<td>20</td>
<td>4.9</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
## Results: Productivity, Stability, and Resilience estimates

Table 2. Value and significance of average Productivity, Stability, and Resilience variables for forage mass of tall fescue half-sib families growing in varying deficit irrigation environments.

<table>
<thead>
<tr>
<th>Crisis environment</th>
<th>Variable</th>
<th>Mean Value</th>
<th>P-value (among HSF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Included in calculation</td>
<td>Productivity(1)</td>
<td>8.989</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td>Stability(1)</td>
<td>2.677</td>
<td>0.6673</td>
</tr>
<tr>
<td></td>
<td>Resilience(1)</td>
<td>5.427</td>
<td>0.0669</td>
</tr>
<tr>
<td>Not included in calculation</td>
<td>Productivity(2)</td>
<td>10.011</td>
<td>0.0094</td>
</tr>
<tr>
<td></td>
<td>Resilience(2)</td>
<td>4.896</td>
<td>0.0617</td>
</tr>
</tbody>
</table>
### Results: $h^2$, $r_G$, and RE of indirect selection for deficit irrigation using Productivity and Resilience estimates

Table 3. Heritabilities, genetic correlations ($r_G$), and relative efficiencies of indirect selection for forage mass of tall fescue under deficit irrigation.

<table>
<thead>
<tr>
<th>Variable/Environment</th>
<th>$h^2$ (±)</th>
<th>$r_G$(Productivity, WL) (±)</th>
<th>RE$_{indirect}$</th>
<th>$r_G$(Resilience, WL) (±)</th>
<th>RE$_{indirect}$</th>
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<tr>
<td>Productivity</td>
<td>0.65 ± 0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resilience</td>
<td>0.44 ± 0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WL1, 110%ET</td>
<td>0.62 ± 0.11</td>
<td>0.91 ± 0.07</td>
<td>0.93</td>
<td>0.29 ± 0.43</td>
<td>0.24</td>
</tr>
<tr>
<td>WL2, 88%ET</td>
<td>0.61 ± 0.11</td>
<td>0.87 ± 0.09</td>
<td>0.90</td>
<td>0.04 ± 0.40</td>
<td>0.03</td>
</tr>
<tr>
<td>WL3, 62%ET</td>
<td>0.46 ± 0.15</td>
<td>0.89 ± 0.10</td>
<td>1.06</td>
<td>0.17 ± 0.48</td>
<td>0.17</td>
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<tr>
<td>WL4, 43%ET</td>
<td>0.56 ± 0.15</td>
<td>0.96 ± 0.11</td>
<td>1.04</td>
<td>-0.20 ± 0.41</td>
<td>-0.18</td>
</tr>
<tr>
<td>WL5, 20%ET</td>
<td>0.62 ± 0.13</td>
<td>0.74 ± 0.20</td>
<td>0.76</td>
<td>0.73 ± 0.17</td>
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### Table 2. Heritability, genetic correlation estimates ($r_G$), and relative efficiency of indirect selection for forage mass of tall fescue under deficit irrigation

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<tr>
<th>Irrigation Level</th>
<th>$h^2$</th>
<th>$r_G$(WL5, WL1)</th>
<th>$RE_{\text{indirect}}$</th>
<th>$r_G$(WL1, WL1)</th>
<th>$RE_{\text{indirect}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WL1, 110% ET</td>
<td>0.62 ± 0.11</td>
<td>0.82 ± 0.23</td>
<td>0.82</td>
<td>- - -</td>
<td>- - -</td>
</tr>
<tr>
<td>WL2, 88% ET</td>
<td>0.61 ± 0.11</td>
<td>0.61 ± 0.25</td>
<td>0.61</td>
<td>0.66 ± 0.20</td>
<td>0.66</td>
</tr>
<tr>
<td>WL3, 62% ET</td>
<td>0.46 ± 0.15</td>
<td>0.72 ± 0.30</td>
<td>0.72</td>
<td>0.17 ± 0.48</td>
<td>0.17</td>
</tr>
<tr>
<td>WL4, 43% ET</td>
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<td>0.53 ± 0.27</td>
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</table>
Top 15% HSF: Mean forage mass and Spearman’s rank correlation from direct and Indirect selection

<table>
<thead>
<tr>
<th>WL1RANK</th>
<th>WL5RANK</th>
<th>PROD2RANK</th>
<th>RESIL2RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.51</td>
<td>0.83</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.58</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Predicted response to selection for increased RESILIENCY

Predicted response to forage mass from selection
(S.I.=15%; k=1.446)

Gain from selection (%) vs. Irrigation level, % ET replacement

R² = 0.9818
Predicted response to selection for increased PRODUCTIVITY, RESILIENCE, or forage mass at 110 and 20% ET
• Univ. of Minnesota 1993, Dr. Don Rasmusson’s Plant Breeding Class:
  – In many instances, selection in a highly-productive, non-target environment is best because it has lower plot variability and higher heritability ------
  – AND translates to higher yield in the stress environment.

Relationship between barley grain yield measured in low- and high-yielding environments

Silvatore Ceccarelli, Stefania Grando & John Hamblin
The International Center for Agricultural Research in the Dry Areas (ICARDA), P.O. Box 5406, Aleppo, Syria

Received: 2 May 1992; accepted: 17 September 1992

Predicting the relative effectiveness of direct versus indirect selection for oat yield in three types of stress environments

Gary N. Atlin* and Kenneth J. Ferrie
Dept. of Agronomy, Iowa State Univ., Ames, IA 50011, USA. *Present address: Biosolvegro Canada Inc., 170, 6811-8 Street N.E., Calgary, Alberta, T2E 7H7, Canada

Received 14 June 1998; accepted in revised form 6 October 1998
Conclusions

- **Resilience** to deficit irrigation can be measured and is a heritable trait – thus resilience can be improved per se by plant breeding.

- **Resilience** to deficit irrigation was not correlated with productivity in ‘non-crisis’ environments.

- Assuming the ‘crisis’ environment can be predicted/simulated, then direct selection within that environment was more effective to improve performance (in this population of tall fescue).

- Selection for increased ‘**Productivity**’ was predicted to improve performance across both crisis and non-crisis irrigation environments.

- What if only examined the immediate recovery after the crisis (e.g., first harvest each year) or used a different irrigation level (e.g., 43% ET replacement) as the ‘crisis’ environment?
Questions