Understanding and quantifying the drivers of seed yield in pulses

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Australian Pulse Conference, 12-14 September 2016, Tamworth
Technological innovation
new combinations of pre-existing elements
Technological innovation new functions – Darwinian pre-adaptations

environment → yield

actual technology

G, M, G x M

potential technology

adoption rate

innovation rate

science, practice

farmer; physiology, genetics, soil...
short term + low aggregation: environment overrides technology
E is often a large source of variation

two exceptions

<table>
<thead>
<tr>
<th>Trait: yield</th>
<th>Crop</th>
<th>E : GxE : G ratio</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>field pea in Canada</td>
<td>31.9 : 2.8 : 1</td>
<td>Yang et al. (2005)</td>
</tr>
<tr>
<td></td>
<td>sunflower in Argentina</td>
<td>4.3 : 1.5 : 1</td>
<td>de la Vega et al. (2007)</td>
</tr>
<tr>
<td></td>
<td>wheat in Australia</td>
<td>3.0 : 2.2 : 1</td>
<td>Cooper et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>sugar beet in Europe</td>
<td>27.5 : 1.1 : 1</td>
<td>Hoffmann et al. (2009)</td>
</tr>
</tbody>
</table>
Crop Science 56 (5) 2016

special issue GxE

13 papers

half define E as location/season
Slide ratio

$E : G \times E : G$  $15 : 7 : 2$
Spatial, probabilistic pattern of drought types for field pea

StressMaster to target specific environment

Soil

Climate (on-site sensor)

Management-to-date
  - Sowing
  - Fertilisation
  - Irrigation
  ...

Irrigation scenarios

Report by email

Terminal drought – a misleading concept

...cognitive structures...interact with grammar...provide conditions for language use...
Chomsky 1998

Chenu et al 2013
Patterns of water stress – pea vs chickpea

The presence of founder crops in the archaeological record of the Levant

Abbo et al 2003 Quarterly Review of Biology 78, 435

Vernalisation:
Abbo 2002 New Phytol 54, 695
Berger et al. 2005 Australian J Agr Res 56, 1191
<table>
<thead>
<tr>
<th>Species</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>onset</td>
</tr>
<tr>
<td>Pea</td>
<td>73.6</td>
</tr>
<tr>
<td>Chickpea</td>
<td>80.3</td>
</tr>
<tr>
<td>Soybean</td>
<td>85.6</td>
</tr>
</tbody>
</table>

Onset and peak temperature for denaturation of seed protein isolates

Withana-Gamage et al. 2011 *J Sci Food Agric* 91:1022
Physiological approach to phenotyping

Crop growth rate derived from NDVI (g m$^{-2}$ oCd$^{-1}$)

Yield (t/ha)

Pea: Sadras et al 2013 *Field Crops Research* 150, 63
Probabilistic thermal regimes for chickpea in Australia

maximum temperature

minimum temperature
Mineralisation (kg N ha\(^{-1}\) month\(^{-1}\))

- erratic summer rainfall
- warm soil
- autumn rainfall break
- mild temp
- end rainfall season
- mild spring temp
- wet but cold winter

Sadras et al. unpublished
How reliable are simulation models?

<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth</td>
<td>****</td>
</tr>
<tr>
<td>Phenology</td>
<td>****</td>
</tr>
<tr>
<td>Water budget</td>
<td>***</td>
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<tr>
<td>Nitrogen budget</td>
<td>**</td>
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<tr>
<td>Biomass partitioning</td>
<td>**</td>
</tr>
<tr>
<td>Extreme events</td>
<td>*</td>
</tr>
<tr>
<td>Pests</td>
<td>*</td>
</tr>
<tr>
<td>Biological aspects of rotations</td>
<td>-</td>
</tr>
</tbody>
</table>
Plasticity: one genotype producing alternative phenotypes in response to environment

+ stress

- stress

Woltereck 1909 Verhandlungen der Deutschen Zoologischen Gesellschaft 19, 110
Reaction norm is the mathematical function
phenotype = f(environment)

Woltereck 1909 Verhandlungen der Deutschen Zoologischen Gesellschaft 19, 110
Methods to quantify plasticity

Slope of reaction norm
- Allows for non-linearity
- Difficult to identify main E

Variance ratio
- Single value of plasticity
- Applies irrespective of E-driver

Yield stability – another misleading concept

Phenotypic plasticity of grain yield

- **Field pea in Australia**
  - \( b = 0.5^* \pm 0.05 \text{ t ha}^{-1} \)
  - \( b = 1.5^{***} \pm 0.23 \text{ t ha}^{-1} \)

- **Sunflower in Argentina**
  - \( b = -3.6^{***} \pm 0.32 \text{ t ha}^{-1} \)
  - \( b = 0.5^* \pm 0.05 \text{ t ha}^{-1} \)
  - \( P = 0.34 \)

- **Wheat in Mexico**
  - \( b = -1.7^{**} \pm 0.54 \text{ t ha}^{-1} \)
  - \( b = 2.0^{***} \pm 0.31 \text{ t ha}^{-1} \)
  - \( P = 0.38 \)

- **Rye in Finland**
  - \( b = 1.5^{***} \pm 0.23 \text{ t ha}^{-1} \)
  - \( b = 2.5^{**} \pm 0.75 \text{ t ha}^{-1} \)
  - \( b = 0.5^* \pm 0.05 \text{ t ha}^{-1} \)


Environment
- ● stress
- ○ potential
Phenotypic plasticity of grain yield

**Environmental stress vs potential**

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Heritability of trait per se

\[ H^2 = (1.89 \pm 0.09) + (-1.19 \pm 0.20) \times MP \]

\[ r = 0.95; p<0.01 \]

Alvarez Prado et al. 2014  *J Exp Bot* 65, 4479
Plasticity and GxE have been running in parallel for over a century
12k “plasticity” papers 1967-2013

Milestones

Richard Woltereck 1909

Anthony Bradshaw 1965

Mary Jane West-Eberhard 2003
Plasticity and GxE have been running in parallel for over a century

Milestones

Richard Woltereck 1909

Anthony Bradshaw 1965
Plasticity is a trait of its own, with its own genetic control

Mary Jane West-Eberhard 2003
Genetic regions associated with trait plasticity in chickpea

Sadras et al. 2016  J. Exp. Bot. 67, 4339
Genetics of crop and plant yield do not match

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