SUGARCANE GENETIC TRAIT PARAMETER ESTIMATION

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Problem

- Conventional sugarcane breeding is resource intensive and slow
- Optimal trait sets are not known
- Breeding targets and screening methods can enhance progress and efficiency

<table>
<thead>
<tr>
<th>Stage</th>
<th># of clones</th>
<th>Sample size</th>
<th># of reps</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery</td>
<td>250 000</td>
<td>1 plant</td>
<td>3/family</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Mini-Lines</td>
<td>175 000</td>
<td>1m</td>
<td>3/family</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Single Lines</td>
<td>20 000</td>
<td>1x5m</td>
<td>1</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Obs plots</td>
<td>3 000</td>
<td>3x6m</td>
<td>3</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Variety trial</td>
<td>120</td>
<td>5x8m</td>
<td>4</td>
<td>5 (10)</td>
</tr>
<tr>
<td>Propagation</td>
<td>20</td>
<td></td>
<td></td>
<td>1 (11)</td>
</tr>
<tr>
<td>Bulking</td>
<td>5</td>
<td></td>
<td></td>
<td>1 (12)</td>
</tr>
<tr>
<td>Release</td>
<td>1 - 3</td>
<td></td>
<td></td>
<td>1 (13)</td>
</tr>
</tbody>
</table>
Trait modelling hypothesis

- Genotype performance (yield) can be predicted realistically by simulating the physiological response to environmental and management factors using genetic trait parameters and environmental data
- Genetic trait parameters can be defined well – predominantly capturing genetic effects
- Genetic trait parameter values can be estimated accurately from reliable and practical phenotypic measurements
- Realistic models with accurate trait parameter values can be used to identify important traits and their ideal values for given environments (including future climate)
- Enhancement of variety improvement programs: Crossing, selection and genetic engineering may be guided by desirable trait sets for target environments
Sugarcane phenotyping issues

• Difficulty in estimating parameter values
  – Often derived indirectly from experimental data (and theory)
  – Need for reference conditions in experiments to minimize environmental impacts
  – Precision, repeatability, ease, cost

• Scarcity of phenotypic data hinders trait modelling progress
Based on observations from numerous variety trials situated throughout the industry.
Aim

Can trait parameter values derived from experimental data and subjective observations predict field performance of sugarcane genotypes?

Objective

Use the Canesim model with parameter values estimated from experimental data and expert ratings to predict stalk dry mass for eight genotypes in two environments in South Africa.
Overview

1. Model and trait parameters
2. Parameter estimation
   - Mount Edgecombe pot trial
   - Expert ratings from variety trials
3. Parameter values
4. Field validation
   - Pongola, Gingindlovu
5. Conclusions
• Model features
  – Canopy cover driven by thermal time and crop water status
  – Multi-layered soil water balance with Penman evapotranspiration and Aquacrop water stress approach
  – Biomass growth based on intercepted radiation conversion and crop water status
  – Biomass partitioning based on development stage, temperature and crop water status

• Inputs
  – Daily weather data
  – Soil water holding capacity and drainage properties
  – Cropping dates, row spacing, ratoon class, soil cover, irrigation data
  – Trait parameters: Thermal time requirements (3), RUEo, biomass partition fractions (3), drought tolerance (1), lodging tolerance (1)

http://www.canesim.co.za/
### Trait parameter estimation

<table>
<thead>
<tr>
<th>Trait</th>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy development rate</td>
<td>TT50</td>
<td>Thermal time to 50% canopy cover (°Cd)</td>
</tr>
<tr>
<td>Onset of stalk growth</td>
<td>TTsg</td>
<td>Thermal time to start of stalk growth (°Cd)</td>
</tr>
<tr>
<td>Maximum photosynthetic</td>
<td>RUEo</td>
<td>Gross photosynthate produced per unit of shortwave radiation intercepted under ideal condition (g/MJ)</td>
</tr>
<tr>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought tolerance</td>
<td>Estress</td>
<td>Relative available soil water threshold below which transpiration is reduced below the potential rate (at AED=5mm/d)</td>
</tr>
</tbody>
</table>
Canopy formation: $TT_{50}$

![Diagram showing canopy cover over thermal time after shoot emergence (°Cd)]
Drought sensitivity: Estress

- **Drought tolerant**
- **Drought sensitive**

**Graph:**
- Y-axis: Relative rate of transpiration and carbon assimilation
- X-axis: Relative available soil water
- Lines show the transition from high to low transpiration rates as soil water availability decreases.
## Canopy formation

### Information Sheet

#### 13. VARIETIES

### 13.3 Variety N12

**INTRODUCTION**
Currently N12 is the most widely grown variety in the rainfall regions of the SA sugar industry. It is a reliable and hardy variety and performs well through the very dry years. To achieve the greatest economic return from this variety it should be planted on average to less favourable areas of the farms. Grey sand, Drakensberg soils and mixed clays Ordinary soil is barely harvested on a long harvesting cycle (16-22 months). N12 must not be harvested at 12 months. The minimum harvest age (months) for the different regions are: North Coast (14), South Coast (15), Coastal Borderland (16), and Midlands (17). N12 has above average P and K requirements.

**Origin:** SASSI, South Africa

**Year of release:** 1959

**Variety code:** N3736

**Parentage:** N6376 × Co371

**Cane Quality & Yield**

- **Tons BPC per hectare:** 50-70
- **Sugar content:** 12.5-13.0% (CSA rating 12)
- **Sap flow:** Above average
- **Reactions to disease:** Average

**REACTIVITY TO DISEASES & PESTS**

- **Stem:** Intermediate
- **Mosquito:** Intermediate
- **RSD:** Intermediate
- **Root:** Resistant
- **Leaf rust:** Resistant
- **Red rot:** Resistant

**Nematode:** Intermediate

**REACTIVITY TO WATER STRESS**

Growth during severe water stress: Moderate to good
Recovery after water stress: Good

**Lodging:** Erect

**Rooting ability (speed and reliability):** Moderate

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Growth during severe water stress: Moderate to good
Recovery after water stress: Good

**Lodging:** Erect

**Rooting ability (speed and reliability):** Moderate

### Experimental data

- **Inman-Bamber (1994):** Data on NCo376, N12
- **Singels & Donaldson (2000):** Data on NCo376, N26, N27
- **Singels et al. (2005):** Data on NCo376, N14, N41
- **Olivier & Singels (2006):** Data on NCo376, N25, N26
- **Rossler (2013):** Data on N14
- **Olivier et al. (2015a):** Data on N14, N26
- **Zhou et al. (2003):** Data on N14, NCo376
- **Olivier et al. (2015b); Weigel et al. (2014)** Data on N19, N31, G73

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### Table: Expert Rating and Genotypes

<table>
<thead>
<tr>
<th>Expert Rating</th>
<th>Genotypes</th>
<th>TT&lt;sub&gt;50&lt;/sub&gt; (°Cd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>1</td>
<td>370</td>
</tr>
<tr>
<td>L</td>
<td>N12, N24, N26, N27</td>
<td>340</td>
</tr>
<tr>
<td>LM</td>
<td>2</td>
<td>310</td>
</tr>
<tr>
<td>M</td>
<td>N28, N39, N41, N47</td>
<td>280</td>
</tr>
<tr>
<td>MH</td>
<td>CP66, N25, NCo376</td>
<td>250</td>
</tr>
<tr>
<td>VH</td>
<td>6</td>
<td>190</td>
</tr>
</tbody>
</table>
# Drought tolerance

<table>
<thead>
<tr>
<th>Expert Rating</th>
<th>Genotypes</th>
<th>Estress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>3</td>
<td>CP66/1043, N14, N19, N22, N24, N26, N28, N30, N32, N35, N37</td>
<td>0.55</td>
</tr>
<tr>
<td>4</td>
<td>N16, N23, N25, N36, N40, N52</td>
<td>0.50</td>
</tr>
<tr>
<td>5</td>
<td>N12, NCo376</td>
<td>0.45</td>
</tr>
<tr>
<td>6</td>
<td>N21, N27, N31, N33, N39, N41, 04G0073</td>
<td>0.35</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>0.30</td>
</tr>
</tbody>
</table>

Experimental data

- Eksteen *et al.* (2014): Data on N19 and 04G0073
- Smit & Singels (2006): Data on NCo376 and N22
- Singels *et al.* (2002); Singels *et al.* (2010): Data on NCo376
• Good agreement between $A$ and $g_{sporo}$ values ($R^2=0.62$) and rankings ($R^2=0.48$)
• Large genetic variation
## Trait parameter estimation

<table>
<thead>
<tr>
<th>Variety</th>
<th>NCo376</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT50 ($^\circ$Cd)</td>
<td>250</td>
</tr>
<tr>
<td>TTsg ($^\circ$Cd)</td>
<td>1000</td>
</tr>
<tr>
<td>RUEo (g/MJ)</td>
<td>2.25</td>
</tr>
<tr>
<td>Estress</td>
<td>0.45</td>
</tr>
</tbody>
</table>

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**Graph:**

The graph shows a scatter plot with a trend line and the equation:

\[ y = 1.0477x + 0.1658 \]

\[ R^2 = 0.8829 \]

**Legend:**

- **Measured stalk dry mass (t/ha)**
- **Simulated stalk dry mass (t/ha)**

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Field trials (Observed data from Ngobese, 2015)

Pongola Irrigated
Oct11-Nov12

Gingindlovu Dryland
Sep11-Oct12
# Field validation: Stalk dry mass

<table>
<thead>
<tr>
<th>Field trial</th>
<th>Observations</th>
<th>Simulations</th>
<th>Rank R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave (t/ha)</td>
<td>Range (t/ha)</td>
<td>LSD (t/ha)</td>
</tr>
<tr>
<td>Pongola</td>
<td>40.4</td>
<td>10.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Gingindlovu</td>
<td>17.6</td>
<td>4.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

\[ y = 0.8837x - 0.9161 \]

\[ R^2 = 0.9624 \]
### Trait impacts on stalk yield

**Table**

<table>
<thead>
<tr>
<th>Trait</th>
<th>Pongola Obs</th>
<th>Pongola Sim</th>
<th>Gingindlovu Obs</th>
<th>Gingindlovu Sim</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT50</td>
<td>-0.376</td>
<td>-0.467</td>
<td>-0.728*</td>
<td>-0.301</td>
</tr>
<tr>
<td>TTsg</td>
<td>-0.603</td>
<td>-0.841*</td>
<td>-0.449</td>
<td>-0.786*</td>
</tr>
<tr>
<td>RUEo</td>
<td>0.809*</td>
<td>0.993*</td>
<td>0.275</td>
<td>0.991*</td>
</tr>
<tr>
<td>Estress</td>
<td>0.122</td>
<td>-0.007</td>
<td>0.523</td>
<td>-0.125</td>
</tr>
</tbody>
</table>

- Observed yields correlate with RUEo (well-watered) and TT50 (water stressed)
- Simulated yields correlated strongly with RUEo and TTsg
Conclusions

• Genotype yield differences under well-watered conditions predicted well from independent trait parameter estimations
• The validity of drought coping traits could not be assessed reliably
• Phenotyping approach (combining experimental measurements with subjective observations) holds promise
• Better grasp of ranges for key parameters
• Canopy development and photosynthetic efficiency are potential traits for screening genotypes for irrigated environments
Acknowledgements

- I. Ngobese for field experimental data
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- National Research Foundation of S.A. for travel funds (Grant no. 77702)
- SASRI for research funding