WATER USE EFFICIENCY AND DROUGHT TOLERANCE OF SUGARCANE FOR BIO-ENERGY PRODUCTION

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BACKGROUND

- The world is desperate for more CO$_2$-neutral energy
- Ethanol and electricity can be obtained from biomass crops
- Sugarcane is a candidate feedstock for bio-energy
  - High biomass yields (up to 250 t/ha)
  - Fermentable sugars (16%)
  - Fibre for cellulosic bio-fuel or electricity (15%)
  - Large existing production areas, surplus sugar
- Indications that high biomass genotypes use water more efficiently than sucrose genotypes
- Opportunity for expansion into marginal areas
OBJECTIVES

• To gather quantitative information on
  – crop productivity (biomass and biofuel),
  – water use efficiency,
  – drought tolerance

• of different sugarcane genotypes

• Benchmark these against other potential bio-energy crops (Sorghum, Sugar beet and Napier grass)

• Assess practical aspects of cultivation
MATERIALS AND METHODS

- Experimental details
- Treatments
- Measurements, calculations
- Climate
Experimental details

- SASRI Mpumalanga Research Station near Komatipoort
- Completely randomised block design (6 genotypes X 2 water regimes X 4 reps)
- Surface drip irrigation system
- Water treatments
  - Well-watered: Replace extraction as measured with neutron water meter
  - Water stress: Irrigate 50% of well watered treatment
# Treatments

<table>
<thead>
<tr>
<th>Crop</th>
<th>Specie</th>
<th>Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane (standard)</td>
<td><em>Saccharum officinarum</em></td>
<td>N19</td>
</tr>
<tr>
<td>Sugarcane (standard)</td>
<td><em>Saccharum officinarum</em></td>
<td>N31</td>
</tr>
<tr>
<td>Sugarcane (Type II)</td>
<td><em>Saccharum spp.</em></td>
<td>04G0073</td>
</tr>
<tr>
<td>Wild sugarcane (Type II)</td>
<td><em>Erianthus arundinaceus</em></td>
<td>IK76-63</td>
</tr>
<tr>
<td>Napier grass</td>
<td><em>Pennisetum purpuream</em></td>
<td>Landrace</td>
</tr>
<tr>
<td>Sorghum/Sudan grass</td>
<td><em>Sorghum spp.</em></td>
<td>Big Kahuna</td>
</tr>
<tr>
<td>Tropical sugar beet</td>
<td><em>Beta vulgaris</em></td>
<td>Phyton</td>
</tr>
</tbody>
</table>
Measurements and calculations

- Interception of photosynthetic active radiation
- Stalk population and height
- Dry mass of components - dead and green leaves, stem sugars and fibres) at 4, 8 and 12 months
- Theoretical ethanol yield from fibre and sugars

Seasonal crop water use
- \( \sum ET = \Delta S + \sum I + \sum Reff - \sum DR \)
- Daily \( Reff = R - 5 \) (canopy interception)
- Daily \( DR = (ASWC + I + Reff - ET_{cane}) - ASWC_{capacity} \)

Water use efficiency
- Aboveground biomass / \( \sum ET \)
- Ethanol production / \( \sum ET \)

Drought tolerance
- \( (\text{Biomass}_{\text{stressed}} / \text{Biomass}_{\text{well watered}}) \times 100 \)
# Measurements and calculations

<table>
<thead>
<tr>
<th>Biomass component</th>
<th>Ethanol yield (l/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem juice sucrose</td>
<td>537</td>
</tr>
<tr>
<td>Stem juice hexoses</td>
<td>510</td>
</tr>
<tr>
<td>Stem fibre: lignin</td>
<td>0</td>
</tr>
<tr>
<td>Stem fibre: cellulose and hemi-cellulose</td>
<td>340 - 385</td>
</tr>
<tr>
<td>Leaf fibre</td>
<td>250</td>
</tr>
</tbody>
</table>
Climate
RESULTS

- Soil water status
- Fractional interception
- Water use
- Biomass
- Biofuel
- WUE
- Drought tolerance
- Agronomy
Soil Water Status

The chart illustrates the soil water status over time, with lines representing different conditions:
- **Irrigation N19 (Well watered)**
- **Rainfall**
- **N19 - Well watered**
- **N19 - Water stressed**
- **04G0073 - Well watered**
- **04G0073 - Water stressed**

The x-axis represents days after the start, while the y-axis shows profile SWC (mm) and irrigation and rainfall (mm). The chart shows fluctuations in water levels over time, with peaks and troughs indicating changes in water availability and usage.
Canopy cover

Fractional interception (%) vs. Days after start for different crops:

- N19 100%
- IK76-63 100%
- Napier grass 100%
- Sorghum 100%
- Sugar beet 100%
Crop water use

Seasonal ET (mm)

- N31
- N19
- 04G0073
- IK76-63
- Napier grass
- Sorghum
- Sugar beet

Crop types:
- Well watered
- Water stressed

Seasonal ET:
- 370 days
- 177 days
- 117 days

Crop water use graph with data points for different crops under well-watered and water-stressed conditions.
Dry biomass yield (t/ha)
Biomass Water Use Efficiency

![Bar chart showing WUE (kg/m^3) for different crops and water conditions.](chart.png)

- **N31**
- **N19**
- **04G0073**
- **IK76-63**
- **Napier grass**
- **Sorghum**
- **Sugar beet**

**Legend:**
- **Well watered**
- **Water stressed**
Biomass Water Use Efficiency

Cumulative ET (mm)

Cumulative dry biomass yield (t/ha)

- $y_{N31} = 0.0497x - 8.7496$
  - $R^2 = 0.9979$
- $y_{N19} = 0.069x - 14.195$
  - $R^2 = 0.9997$
- $y_{04G0073} = 0.0416x - 2.0883$
  - $R^2 = 0.8371$
- $y_{Napiergrass} = 0.0548x + 1.7089$
  - $R^2 = 0.9692$
Biomass Water Use Efficiency (kg/m³)

<table>
<thead>
<tr>
<th>Genotype</th>
<th>100%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N19</td>
<td>6.9</td>
<td>8.13</td>
</tr>
<tr>
<td>N31</td>
<td>4.97</td>
<td>7.01</td>
</tr>
<tr>
<td>G73</td>
<td>4.16</td>
<td>6.68</td>
</tr>
<tr>
<td>Napier grass</td>
<td>5.48</td>
<td>6.29</td>
</tr>
</tbody>
</table>

- Sugarcane literature: 2.5 – 5.0
Biofuel Water Use Efficiency

Water use efficiency (l/m³)

- N19
- N31
- G73
- IK7663
- Napiergrass
- Sorghum
- Sugar beet

100%
50%
Agronomic Issues

- **04G0073 – Early flowering**
- **IK76-63 – Poor germination**
- **Sugar beet – Healthy leaves**
- **Sugar beet – Leaf diseases**
- **Sorghum – Stalk borer**
- **Napier grass – Self trashing**
- **Napier grass – Self trashing**
CONCLUSIONS

- Highest biomass and bio-fuel yield was achieved by N19 followed by N31, Napier grass, IK63 and G73.
- Highest biomass and biofuel WUE achieved by sugar beet, followed by sorghum and N19, lowest by G73*.
- A combination of sorghum and sugar beet produced most biomass in one year and had highest WUE (by far).
- Drought tolerance: High biomass sugarcane G73 and sorghum seems more drought tolerant than standard sugarcane and other crops*.
- Productivity affected by flowering, trashing, pest and diseases.
- Quantitative data on resource capture, resource conversion efficiency and drought tolerance will aid spatial modelling of crop productivity and water use.
Take Home Messages

Suitability for biofuels

• Sugar beet/sorghum combination most productive and water use efficient option
• Conventional sugarcane cultivars can compete with biomass crops for ethanol production due to ease of cultivation and processing versatility

Way forward

• Test more biomass cultivars
• Refine crop models and spatially estimate biomass and energy productivity and water use for existing and new sugarcane production areas
• Quantify nitrogen requirements
• Determine economics of production
ACKNOWLEDGEMENTS

• SASRI technicians
• Former Ph.D. student Yuri Tsupko
• Sugarcane Industry funding
Drought Tolerance

![Graph showing relative stalk height (%)]
Biofuel yield

![Graph showing biofuel yield for different genotypes.](image-url)
## Agronomic Issues

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>N19 and N31</td>
<td>Lodged in September</td>
</tr>
<tr>
<td>04G0073</td>
<td>Flowered in June, lodged in September</td>
</tr>
<tr>
<td>IK76-63</td>
<td>Poor and slow germination</td>
</tr>
<tr>
<td>Napier grass</td>
<td>Self trasharing</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Poor germination, stalk borer and aphids required regular control</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>Poor germination required gap re-planting, diseases required control</td>
</tr>
</tbody>
</table>
Values of WUE ranging from 3.3 to 4.6 g kg⁻¹ for the perennial C4 grasses in the present study were comparable to median values of 4.2 reported for grain sorghum (Sorghum bicolor L.), 3.9 for pearl millet, and 4.8 g kg⁻¹ for maize [31]. Agriculture 2012, 2, 325-338; doi:10.3390/agriculture2040325