Recent and Future Yield Increases

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Topics

Contributions to recent yield increases
- Weather (UK)
- Varieties and agronomy (UK)

Contributions for the future
- CO₂
- Climate (UK & US)
- Technology and the yield gap (UK & US)
Units

- I will use t/ha of sugar (raw, not recoverable)
- 1t/ha is ~ 800 lbs/ac recoverable
- A big sugar yield is 15 t/ha (12,000 lb/ac recoverable)
Where?
Contributions to Recent Increases

• plant breeding?
• agronomy and crop protection?
• the environment?
Sugar yields in UK variety trials and commercial crops since 1976

Crop year

Sugar yield (t/ha)

Commercial crops
Variety trials

Crop year

Sugar yield (t/ha)
March – October weather across 18 weather stations in UK beet growing areas.
BB sugar beet growth model

- Sowing date
- Harvesting date
- Global radiation
- Temperature
- Rainfall PET
- Soil texture
- Latitude

Cultivar is not an input
The time step is daily
Model works well in many conditions
Simulated yield trend using mean sowing date

\[ y = -267.3 + 0.139 \times x \]
UK annual 50% crop sowing date

Crop Year

Sowing date (Julian day of the year)
70 80 90 100 110 120

Crop Year
Allocation of the annual yield increase rate (t/ha/year) that was measured in UK variety trials: 1976 - 2005

<table>
<thead>
<tr>
<th>Source of annual increase</th>
<th>t/ha/a</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earlier sowing</td>
<td>0.025</td>
<td>12</td>
</tr>
<tr>
<td>Climate change</td>
<td>0.140</td>
<td>56</td>
</tr>
<tr>
<td>Residual (agronomy and vars.)</td>
<td>0.065</td>
<td>32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.204</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Weekly sampled versus simulated sugar yield in 2004

Sugar yield (t/ha)

Sampling date

Sampled
Modelled
Weekly sampled versus simulated sugar yield
Comparison of observed with simulated growth and sugar yield using the old model

Simulated sugar yield (t/ha)

Observed sugar yield (t/ha)

Simulated total dry matter (t/ha)

Observed total dry matter (t/ha)

Broom's Barn Irrigated
Broom's Barn Rainfed
Cavenham
Littleport
Holbeach

x=y

EF=80.7%
RMSE=4.9
MAE=3.8

EF=82.2%
RMSE=2.5
MAE=2.0
Observed versus simulated canopy cover with the old model

\[ f = f_0 \exp \left( \mu_{\text{min}} (T - T_0) + \frac{\mu_0 - \mu_{\text{min}}}{\nu} \left(1 - e^{-\nu(T - T_0)}\right) \right) \]
Observed and simulated allocation of dry matter to sugar: old model

Y = W - \frac{1}{k} \log(kW + 1)
Today, autumn foliage tends to be healthier and more extensive.

September 2000

28 October 2011
Observed and simulated sugar yield: recalibrated model

- Broom’s Barn irrigated
- Broom’s Barn rain-fed
- Cavenham
- Littleport
- Holbeach

Sugar yield (t/ha) vs. Harvest date (Julian day of the year)
Sampled and simulated sugar yield: recalibrated model

Sugar yield (t/ha)

Sampling date

2008

2009

2010

2011
Recent yield increases in UK were about 20%:

- from primed beet seeds which gave earlier seedling emergence
- **NOT** from faster canopy growth or from better allocation of dry matter to sugar (a big surprise)
- from better radiation use efficiency in late summer and autumn (variety and fungicide effects)
Possible Sources of Future Increases

• Extra CO$_2$

• A changed climate

• Plant breeding & technology
Past and future $\text{CO}_2$ concentrations

Most scenarios assume c. 550 ppm by 2050
Free Air CO$_2$ Experiments

Sugar yield increased by 15% at 550ppm
Climate Change

• Assumed CO₂ concentrations

<table>
<thead>
<tr>
<th>Decade</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000s</td>
<td>367</td>
</tr>
<tr>
<td>2020s</td>
<td>418</td>
</tr>
<tr>
<td>2050s</td>
<td>523</td>
</tr>
</tbody>
</table>

• Ensemble of 17 GCMs
• Two areas: East England & central N. America
• Simulated daily weather for 10 years
US region covered by future climate projection
Monthly mean air temperature increase over baseline 2000s in East England

Warmer by 1 - 3°C
Monthly mean air temperature increase over baseline 2000s in RRV

Warmer, especially in late winter and spring
Monthly precipitation change over baseline 2000s in East Anglia, England

Drier summer
Monthly precipitation change over baseline 2000s in RRV

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm)</td>
<td>-30</td>
<td>-20</td>
<td>-10</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
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Wetter summer

- Wetter summer
Median sugar yield simulations for beet in England

- Scenarios: 2000s, 2020s, 2050s
- Median yield (t/ha)
- Soil types: Clay loam, Sandy, Sandy loam, Silt

Graph showing the increase in median yield for different soil types over three scenarios.
Climate change effects on simulated mean sugar yields (%)

<table>
<thead>
<tr>
<th>Decade</th>
<th>UK</th>
<th>RRV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000s</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2020s</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>2050s</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

UK values adjusted for sowing date (4 & 10 days earlier)
Technology
(breeding, agronomy and yield gap)

England

Sugar (t/ha)


\[ y = 0.277x - 548.1 \]

American Crystal Sugar

Sugar (t/ha)


\[ y = 0.337x - 667.8 \]
Technology
(breeding, agronomy and yield gap)

• Commercial increase rates are similar, about 0.3t/ha per year
• Part of the effect is climate change (0.14t/ha per year)
• Can we expect changes in technology to continue to deliver 0.16t/ha per year?
• Why not? In the last decade it delivered about 20% more yield in the UK, so there is no yield plateau yet.
Can we close the yield gap?

- Difference between potential yield and delivered yield
- Closing the gap is considered a good way to increase delivered yield
- Potential might be measured in variety trials
Yield Gap

Gap due to:

- water stress in commercial crop
- storage losses
- post harvest handling
- occasional crop failure
- weeds, pests and diseases
Yield Gap

England

\[ y = 0.375x - 738.5 \]

\[ y = 0.277x - 548.1 \]

American Crystal Sugar

\[ y = 0.132x - 255.3 \]

\[ y = 0.337x - 667.8 \]
### Possible sugar yields (t/ha)?

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<thead>
<tr>
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<th>RRV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000’s</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>2020’s</td>
<td>14.8</td>
<td>14.7</td>
</tr>
<tr>
<td>2050’s</td>
<td>19</td>
<td>18.7</td>
</tr>
</tbody>
</table>

Values are today’s yield plus allowances for CO₂ effect, climate change and a continuation of the technology effect measured since 2000.
Climate change and the process
UK warmer winters

Reduced freezing risk for very late harvest
Could UK plan to run for another 2 weeks?
Monthly mean air temperature increase over baseline 2000s in RRV

Warmer winter. Will the piles stay frozen?
Thank you
for inviting me to speak
and for your attention