Potentials and limits of early-maturing varieties to reduce climate-risks of smallholder intensification pathways

Uwe Grewer\textsuperscript{1,2}, Peter de Voil\textsuperscript{1}, Dilys MacCarthy\textsuperscript{3}, Daniel Rodriguez\textsuperscript{1}

\textsuperscript{1} Queensland Alliance for Agriculture and Food Innovation, University of Queensland
\textsuperscript{2} Commonwealth Scientific and Industrial Research Organisation (CSIRO)
\textsuperscript{3} Soil and Irrigation Research Centre, University of Ghana

7\textsuperscript{th} International Farming Systems Design Workshop
30 October – 3 November 2022, Marrakech, Morocco
Weather conditions in smallholder agriculture

• Across smallholder cropping systems in sub-Saharan Africa crop yield and the adoption of intensification practices & technology remain comparably low despite their wide promotion.
• Particularly drought may limit, expected and actual, yield gains from the application of high-yielding, late-maturing varieties and synthetic fertilizer.
• Weather-induced production risk effectively functions as a central barrier to the adoption of costly intensification practices and technologies.
Value proposition from early-maturing cultivars

- Early-maturing crop cultivars have been widely promoted as potential pathway to:
  - Limit the probability of being exposed to weather-induced production risks
  - Provide a pathway to more safely commit limited resources to “intensified” cropping systems
  - Offer novel farming systems design options due to reliable production potential during the minor growing season (in bi-modal production locations)
Research questions

Here, we investigate for maize in Ghana:

- If the benefits of applying early-maturing maize varieties strongly depends on the timing of drought events:
  - Do early-maturing varieties do not provide any benefit under early-season drought?
- How strongly do yield-benefits vary across spatial scales / should they only be promoted in specific locations?
- How much yield potential is foregone under (above-) average seasonal conditions?
Gridded crop modelling

- Gridded maize modelling across a 0.1-decimal degree grid in Ghana using APSIM (v7.10)
- Treatments:
  - 3 levels of N-fertilization: 0, 45, 90 kg N / ha
  - 3 planting densities: 4.4, 5.6, 6.7 plants / m²
  - 3 cultivar maturity types
- 30 years of weather data (1987 – 2016):
  - Precipitation data (daily; 0.05 dd): Climate Hazards center InfraRed Precipitation with Stations dataset
  - Temperature data (daily; 0.05 dd): Climate Hazards center InfraRed Temperature with Stations dataset
  - Solar radiation and wind speed (daily; 0.1 dd): AgERA5
- Soils data (5 arc-min): Global High-Resolution Soil Profile Database for Crop Modeling Applications (Han et al., 2015) based on ISRIC-1km and AfSIS
APSIM calibration & evaluation

• APSIM calibration & evaluation for major national Obatampa variety using three years of data from one location in Southern Ghana (major limitation)
• Hypothetical definition of an earlier & later maize variety by changes to thermal time requirements:

<table>
<thead>
<tr>
<th></th>
<th>early (hypothetical)</th>
<th>medium (calibrated)</th>
<th>late (hypothetical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>emergence:end juvenile</td>
<td>310</td>
<td>340</td>
<td>370</td>
</tr>
<tr>
<td>flowering:maturity</td>
<td>780</td>
<td>810</td>
<td>840</td>
</tr>
</tbody>
</table>

• Computation of a year-specific start date of the agricultural growing season (used as start of planting window) based on a meteorological criterion:
  o Observation of >40mm of precipitation during a five day period (season onset),
  o Without any ten day period in the subsequent 30 days observing <5mm of precipitation (false onset).
  o Without any 15 day period in the subsequent 90 days observing 0mm precipitation
  o With at least 500 mm precipitation over the full growing season
• Locations that observe less than 20 valid major growing seasons are excluded from the analysis
Descriptive statistics of water stress conditions
Highest water deficits are during the early season and quite uniformly across entire country.

Mid- and late-season sees higher spatial variability & a more abundant water balance.

Late-season is highly more variable than the early-season.
Descriptive aggregate simulation results

Descriptive statistics of national level & 30-year averages
• Typical yield-potential & -variability divergence between southern & northern production locations

• In terms of nationally aggregate yield:
  o early-maturing cultivars are outperformed by medium- & late-maturing cultivars across all treatments
  o Only in year with highest drought & N-application, early-maturing cultivars provide higher national average yield
Aggregate yield risk profiles

When considering the average across all production locations:

- No N treatments have the expected higher risk profile than production systems receiving N inputs
- Different cultivars do not show any major distinction in risk profiles (no crossing CDF curves / no major differences in shape)
Spatial variation in long-term average yield by cultivar

- All three cultivars show a rather identical spatial pattern in terms of:
  - the long-term average yield
  - the long-term yield variability
  - the probability to observe less than 1500 kg/ha
Analytical simulation results: aggregated approach

Multi-variate regression analysis: identical coefficients across locations
Random effects model

\[ q_{it} = \alpha + \sum_{j=1}^{J} \delta_j \ln z_{jit} + \sum_{m=1}^{M} \beta_m \ln x_{mit} + \sum_{h=1}^{H} \sigma_h r_{ht} + \varepsilon_{it} \]

Where:

- \( i \): location
- \( t \): year
- \( q_{it} \): yield (at location \( i \) in year \( t \))
- \( z_{it} \): vector of environmental variables (at location \( i \) in year \( t \))
- \( x_{it} \): input vector (at location \( i \) in year \( t \))
- \( r_{t} \): location random-effect (in year \( t \))
- \( \varepsilon_{it} \): error term (at location \( i \) in year \( t \))
Estimation results

<table>
<thead>
<tr>
<th>Estimate</th>
<th>Std. Error</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>4195</td>
<td>12.8</td>
</tr>
<tr>
<td>ObatanpaEarly</td>
<td>-175</td>
<td>5.12</td>
</tr>
<tr>
<td>ObatanpaLate</td>
<td>92</td>
<td>5.12</td>
</tr>
<tr>
<td>fertQtN</td>
<td>-2.2</td>
<td>0.07</td>
</tr>
<tr>
<td>plantDensity</td>
<td>-262</td>
<td>0.77</td>
</tr>
<tr>
<td>EDD_season</td>
<td>-13</td>
<td>0.03</td>
</tr>
<tr>
<td>WatBal_GS_early</td>
<td>413</td>
<td>3.04</td>
</tr>
<tr>
<td>WatBal_GS_mid</td>
<td>102</td>
<td>1.76</td>
</tr>
<tr>
<td>WatBal_GS_late</td>
<td>46</td>
<td>0.83</td>
</tr>
<tr>
<td>fertQtN:plantDensity</td>
<td>6.3</td>
<td>0.01</td>
</tr>
<tr>
<td>ObatanpaEarly:WatBal_GS_early</td>
<td>64</td>
<td>4.15</td>
</tr>
<tr>
<td>ObatanpaLate:WatBal_GS_early</td>
<td>-30</td>
<td>4.15</td>
</tr>
<tr>
<td>ObatanpaEarly:WatBal_GS_mid</td>
<td>-10</td>
<td>2.25</td>
</tr>
<tr>
<td>ObatanpaLate:WatBal_GS_mid</td>
<td>2.2</td>
<td>2.25</td>
</tr>
</tbody>
</table>

- On average, the early-maturing cultivar yields 175 kg less, and the late-maturing cultivar 92 kg more than the medium-maturing cultivar (i.e. spread of 6% of overall yield potential)
- As expected, water conditions during the early growing season are decisively more influential than during the mid growing season, while late-season conditions have the least relevant impact.
- If water-deficits are observed during the early growing season, the early-maturing cultivar comparably suffers strongest, and the late-season cultivar least.
- If positive water-balance is observed during the early growing season, the early-maturing cultivar benefits most, but still does not reach the yield potential of the other varieties if water-conditions are not highly extraordinary
- If water-deficits are observed during the mid growing season, the early-maturing cultivar suffers least, and the late-season cultivar strongest (impact strength is low)
Analytical simulation results: disaggregated approach

Multi-variate regression analysis: location-specific coefficients
Location specific estimation

• We re-estimate the presented econometric model (without any random effect) separately for each considered location (i.e. all coefficients & the intercept are allowed to vary by location)
• This allows to identify if there are strong spatial discrepancies in the estimated strength of yield drivers
• Fertilizer impacts are sizably stronger in Northern Ghana where soil organic carbon levels are low
• Likewise in the north, high levels of plant density do often reduce yield (even on average across all N treatments)
• Extreme degree days can moderately decrease yield in the north-west, while being largely irrelevant in all other locations
• A favourable early- (and mid-) season water balance benefits Central and Southern Ghana much stronger than the North
Across large spatial scales, the different varieties are not found to have largely different yield potential. However, in selected locations, the impact of using certain maturity groups can be very strong. In selected locations in Central-Southern Ghana, the early-maturing variety is found to provide up to 1000 kg less yield than the medium-maturing variety; while the late-maturing variety provides advantages there. Positive impacts of early-maturing varieties are largely confined to northern Bono and southern Savannah region. Late-maturing varieties show comparably very low performance south of Nkawkaw.
Conclusions

• This is work in progress: Results not set in stone and should not be used for policy advice
• Maturity-duration did not proof to be a major yield driver across most locations – but in few selected locations impacts can be very strong
• There is the expected relationship that early-maturing varieties on average provide lower yield (though not by much), while themselves being highly sensitive to water availability early in the season
• Locations that regularly observe water-scarcity in the early season may thus be reasonably avoided when targeting the adoption of early-maturing varieties

• Further discussion is needed on how we can use statistical techniques to provide useful and adequate summaries of large-scale simulations
• Non-linear regression and non-parametric approaches may provide alternative methods (though at high costs)
Thank you!

Work in progress, comments welcome!

Uwe Grewer | PhD candidate
Queensland Alliance for Agriculture and Food Innovation (QAAFI),
The University of Queensland
&
Commonwealth Scientific and Industrial Research Organisation (CSIRO)

u.grewer@uq.edu.au
qaafi.uq.edu.au

The Queensland Alliance for Agriculture and Food Innovation (QAAFI) is a research institute of The University of Queensland (UQ), supported by the Queensland Government.