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

Uwe Grewer[1,2], Peter de Voil[1], Dilys MacCarthy[3], Daniel Rodriguez[1]

[1] Queensland Alliance for Agriculture and Food Innovation, University of Queensland

[2] Commonwealth Scientific and Industrial Research Organisation (CSIRO)

[3] Soil and Irrigation Research Centre, University of Ghana

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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 / m^2
  - 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

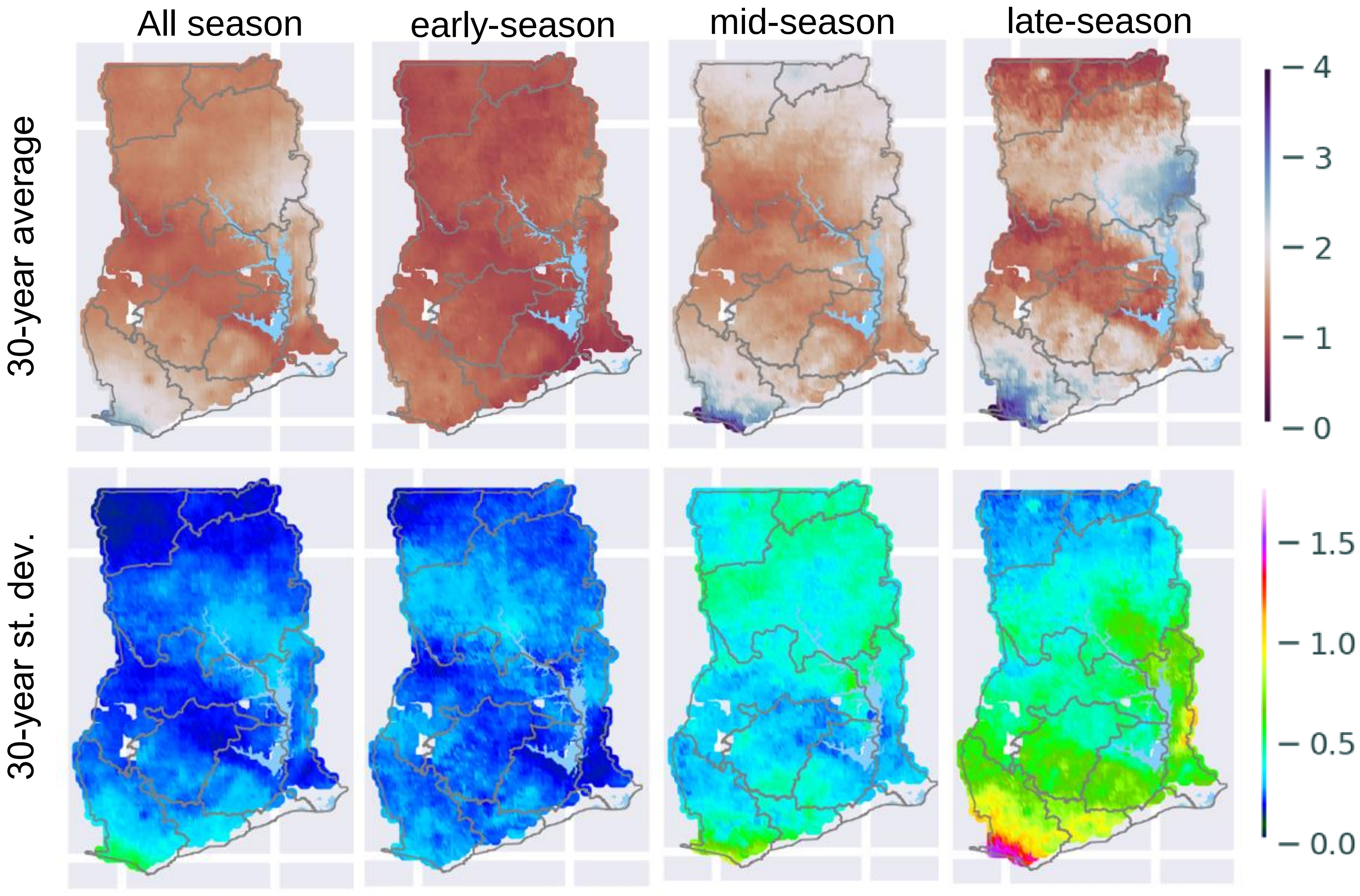
- APSIM calibration & evaluation for major national Obatampa variety using three years of data from one location in Southern Ghana (major limitation)
- Hypothetical definition of an earlier & later maize variety by changes to thermal time requirements:

	early (hypothetical)	medium (calibrated)	late (hypothetical)
emergence:end juvenile	310	340	370
flowering:maturity	780	810	840

- Computation of a year-specific start date of the agricultural growing season (used as start of planting window) based on a meteorological criterion:
  - Observation of >40mm of precipitation during a five day period (season onset),
  - Without any ten day period in the subsequent 30 days observing <5mm of precipitation (false onset).
  - Without any 15 day period in the subsequent 90 days observing 0mm precipitation
  - 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

Water-balance ratio: precipitation / ref. evapotranspiration

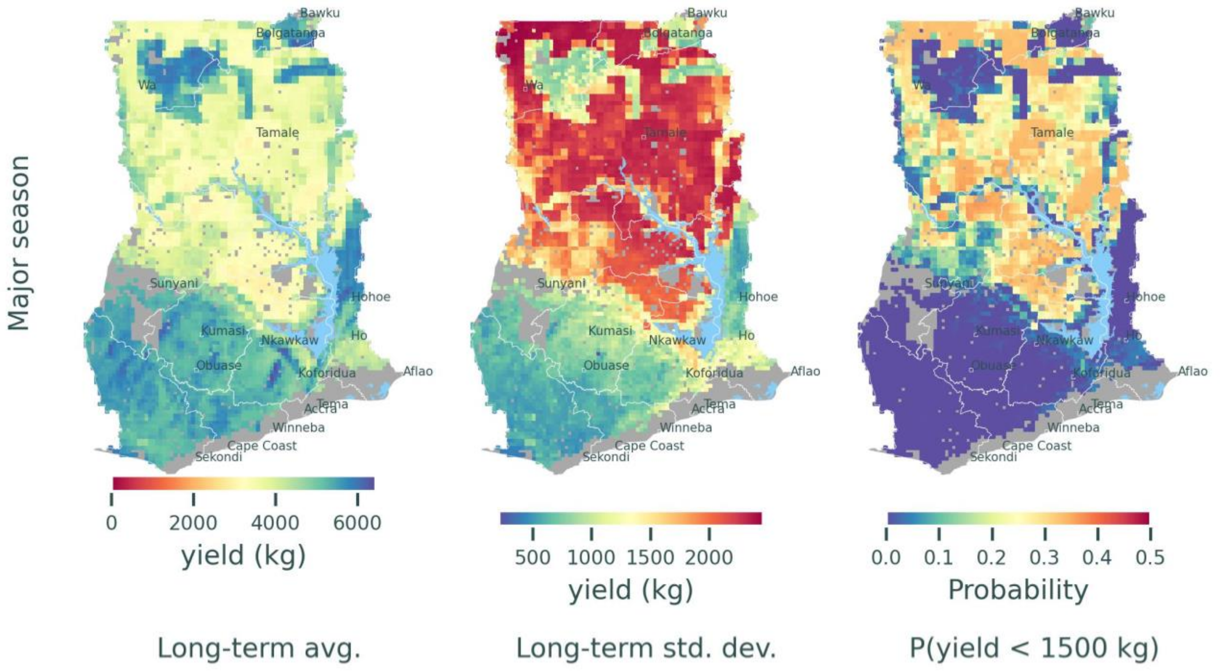


- Highest water deficits are during the early season and quite uniformly across entire country
- Mid- and late-season sees higher spatial variability & a more abundant water balance
- Late-season is highly more variable than the early-season

Descriptive aggregate simulation results

Descriptive statistics of national level & 30-year averages

Aggregate simulation results (time & space)

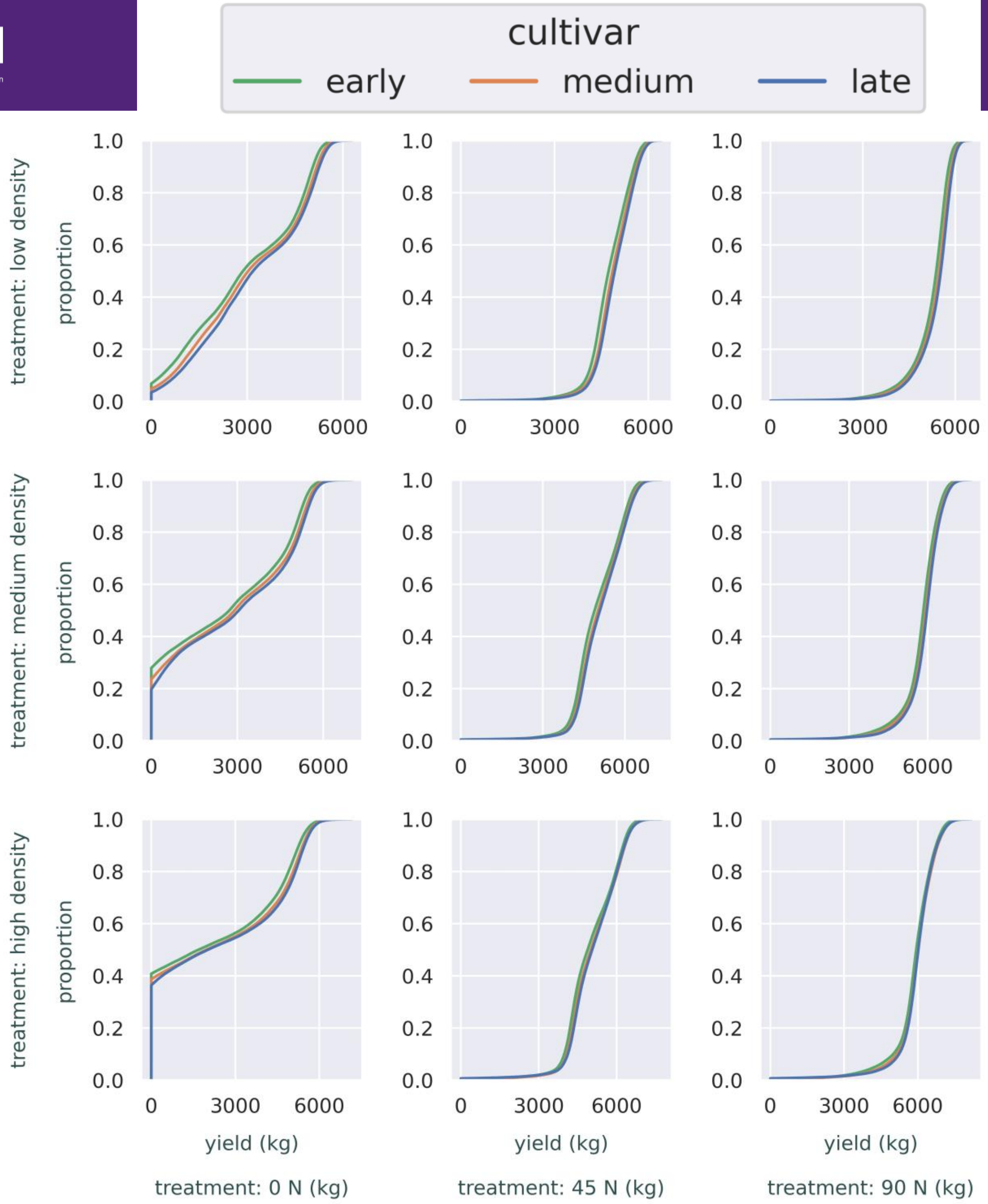


- Typical yield-potential & -variability divergence between southern & northern production locations
- In terms of nationally aggregate yield:
  - early-maturing cultivars are outperformed by medium- & late-maturing cultivars across all treatments
  - Only in year with highest drought & N-application, early-maturing cultivars provide higher national average yield

Aggregate yield risk profiles

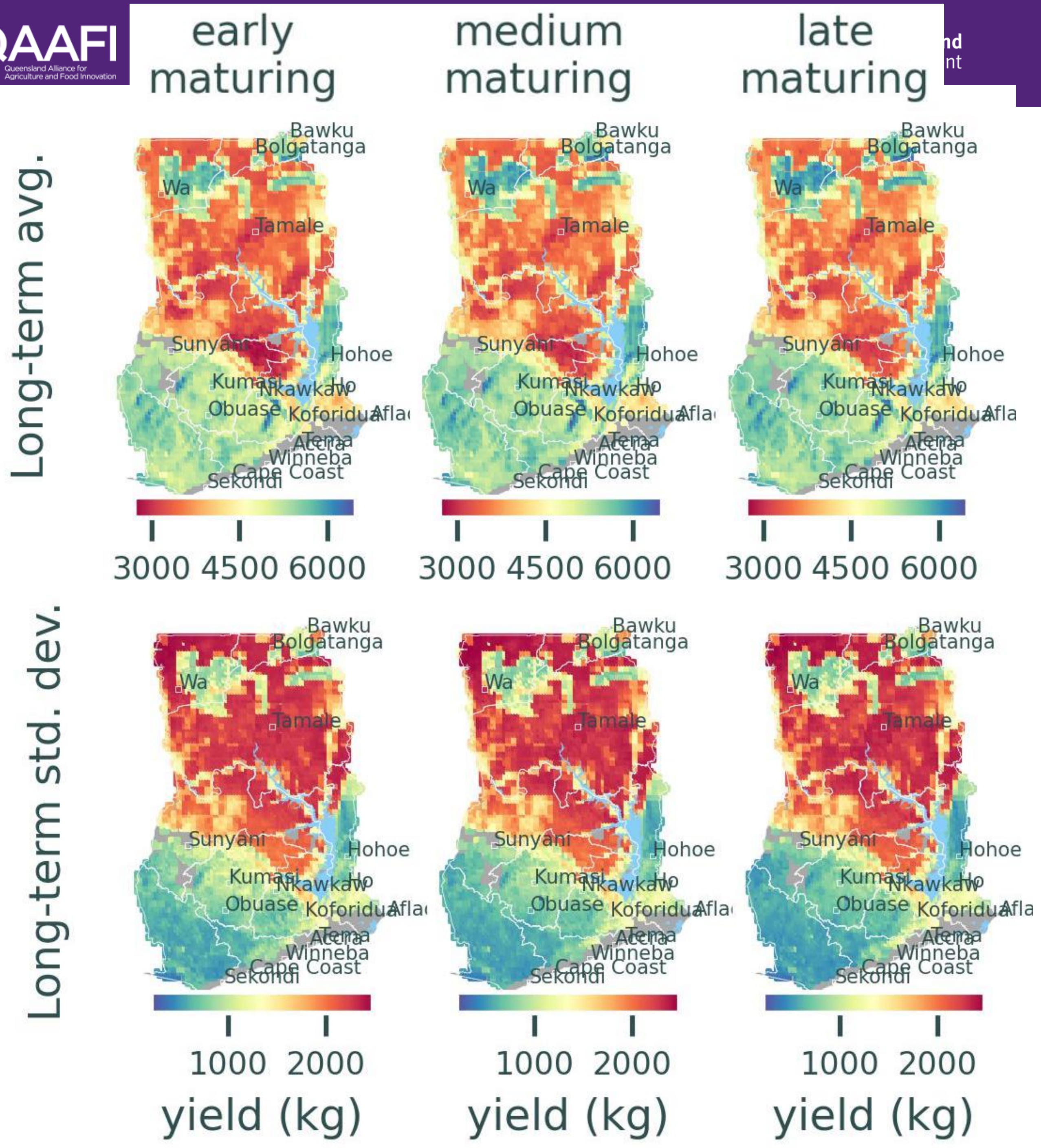
When considering the average across all production locations:

- 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

$$\boldsymbol{q}_{it} = \alpha + \sum_{j=1}^{J} \delta_j \, ln \, z_{jit} + \sum_{m=1}^{M} \beta_m \, ln \, x_{mit} + \sum_{\mathbf{h}=1}^{\mathbf{H}} \boldsymbol{\sigma}_h \, \boldsymbol{r}_{ht} + \boldsymbol{\varepsilon}_{it}$$

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)
v_{it}	error term (at location i in year t)

Estimation results

	Estimate	Std. Error	t value
(Intercept)	4195	12.8	327.7
ObatanpaEarly	-175	5.12	-34.23
ObatanpaLate	92	5.12	17.92
fertQtN	-2.2	0.07	-29.41
plantDensity	-262	0.77	-341.37
EDD_season	-13	0.03	-388.45
WatBal_GS_early	413	3.04	136.06
WatBal_GS_mid	102	1.76	58.30
WatBal_GS_late	46	0.83	54.79
fertQtN:plantDensity	6.3	0.01	474.52
ObatanpaEarly:WatBal_GS_early	64	4.15	15.33
ObatanpaLate:WatBal_GS_early	-30	4.15	-7.20
ObatanpaEarly:WatBal_GS_mid	-10	2.25	-4.65
ObatanpaLate:WatBal_GS_mid	2.2	2.25	0.96

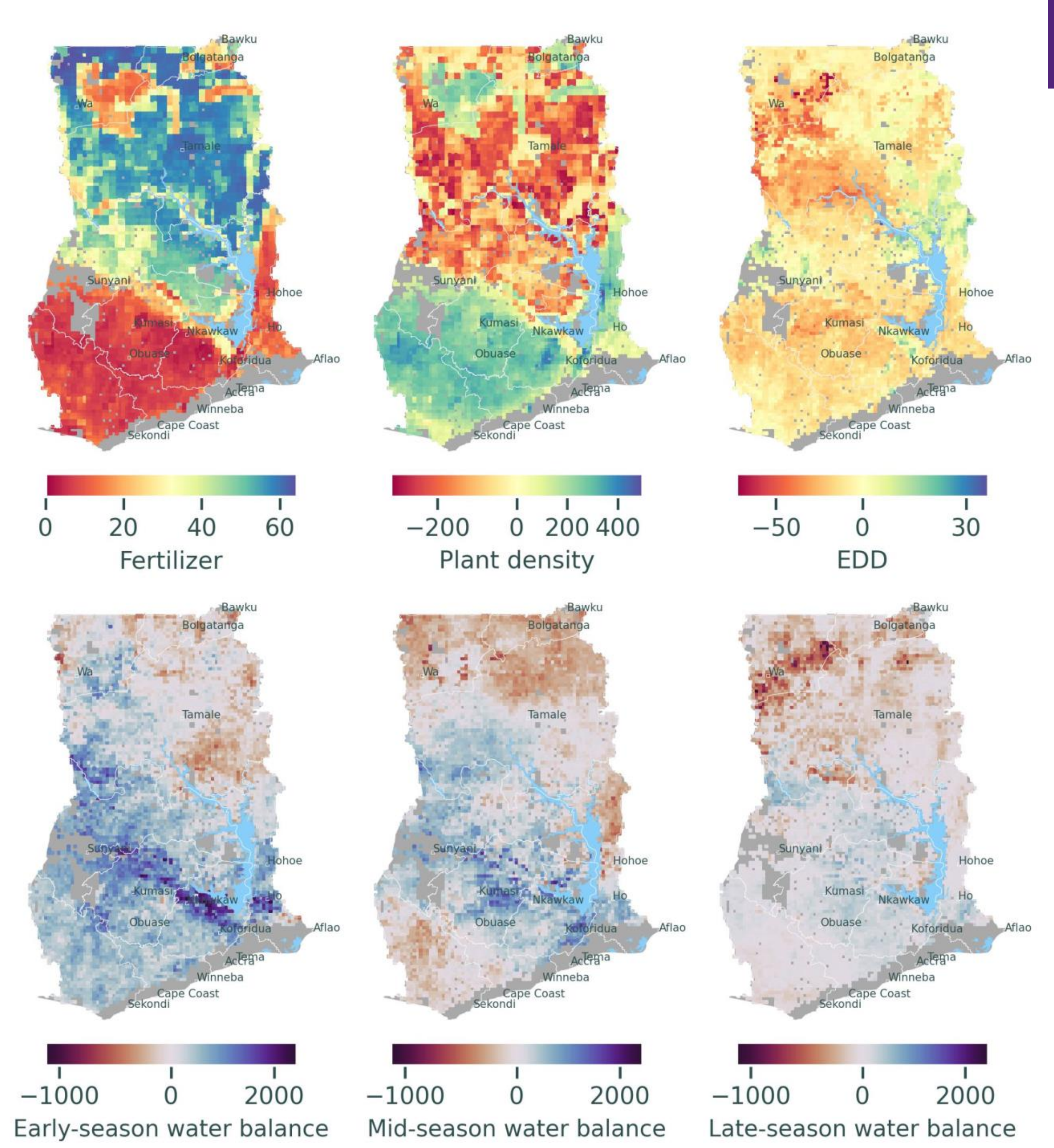
- On average, the early-maturing cultivar yields 175 kg less, and the late-maturing cultivar 92 kg more than the medium-maturing cultivar (i.e. spread of 6% of overall yield potential)
- As expected, water conditions during the early growing season are decisively more influential than during the mid 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

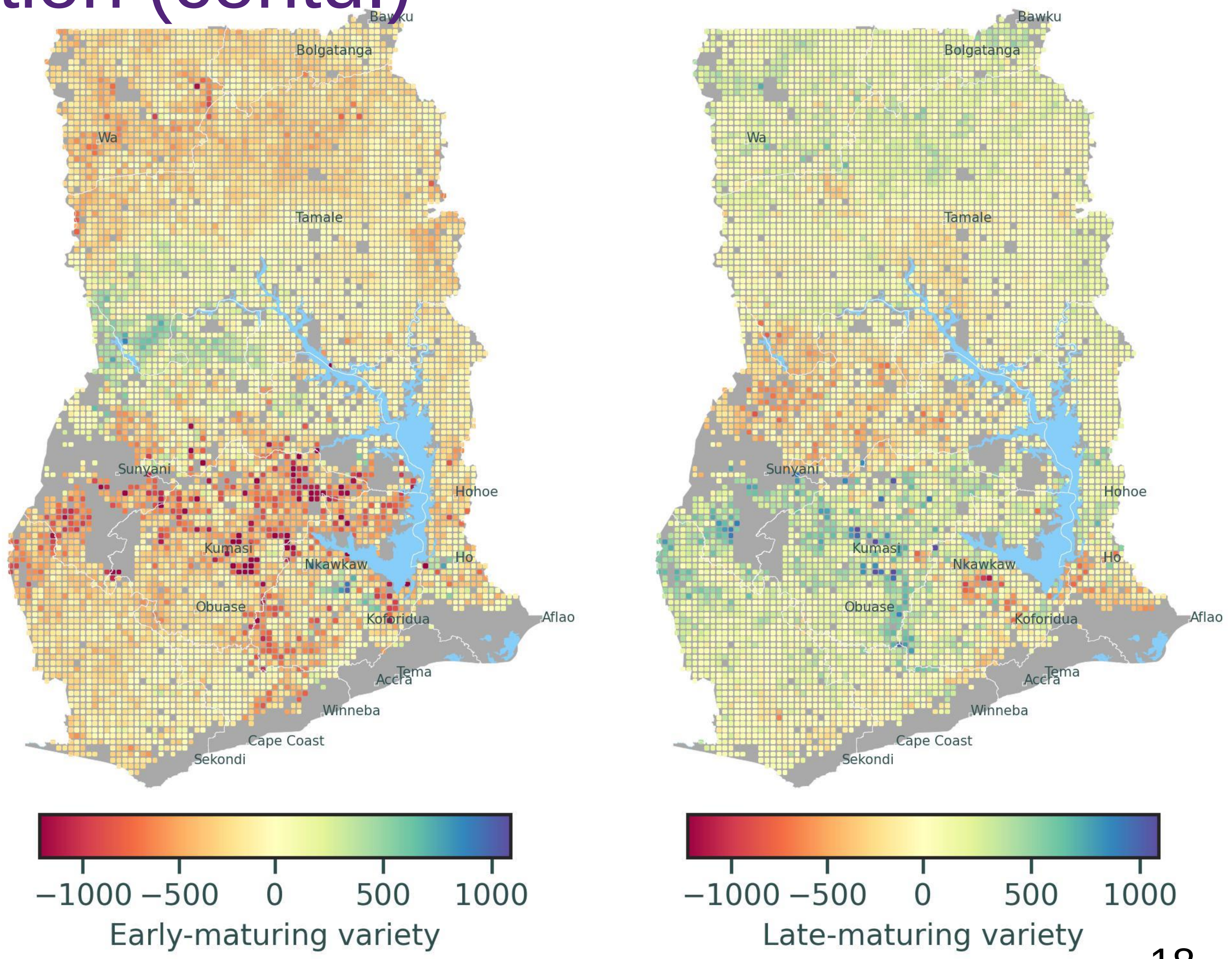
Location specific estimation

- 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



Location specific estimation (contd.)

- 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

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