Climate Change Impacts on Rain-fed Agriculture and Crop Yields in the Niger Basin

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Importance of Rain-fed Agriculture

- Represents 95% of cultivated land area.
- Accounts for 35% of GDP, on average.
- Employs 70% of the population. (FAOSTAT, 2005).

- Very risky due to variable rainfall, dry spells, recurrent droughts, long dry seasons, floods, or extreme rainfall.
- Limited to no insurance in SSA against weather hazards and extremes.
- Majority of farmers have small farm holdings of < 2 ha.
- Poor investments; < 10% of investments in irrigated agriculture.
While irrigation is critical and necessary, it will NOT by itself alone assure food security because of constraints related to affordability of water, access and tenure to irrigation lands, and inertia on the part of farmers to convert from rain-fed agricultural systems to irrigation.

Large scale or widespread irrigation outside riparian environments highly unlikely in SSA due to the size and yield of groundwater aquifers as well as the lack of investment.

Therefore, in order to achieve maximum impact for food security, climate risk assessment and climate adaptation (planning and management) must include both irrigated and rain-fed agriculture.
Predicted impact of climate change on cereal productivity in Africa

Map showing the projected impact of climate change on cereal productivity in Sub-Saharan Africa, with a scenario showing CO₂ atmospheric concentrations at a level of 520-640 ppm by 2050. The map highlights areas affected by climate change, with color coding indicating the percentage change in cereal productivity from 2000 to 2080.

Key affected areas:
- The Sahelain belt: Burkina Faso and cultivated regions of southern Mali, Niger, Chad and Sudan (northern parts of country uncultivated or unsuitable for cereal production).
- Nigeria, Senegal and Sierra Leone (West Africa).
- Eastern Ethiopia and Somalia.
- Southern east Africa: Mozambique, Zimbabwe, Zambia and Angola.

In SSA, > 100 million people live in the areas expected to experience the most reductions in cereal productivity as a result of climate change.

Fig. 2.3. Number of people living in water-constrained, rainfed agricultural areas. The three circles indicate the occurrence of global hotspots where more than 100 million people live.
Even without climate change, cereal yields in most SSA countries are only about 35% of potential, creating a "yields gap" due to inefficient management methods, soil nutrient status and climate risks.

**Fig. 1.3.** Examples of observed yield gap (for major grains) between farmers’ yields and achievable yields (100% denotes achievable yield level, and columns actual observed yield levels) (Source: derived from Rockström et al., 2007).
Research Objectives

- To estimate climate risks to major staple crops in semi-arid West Africa at selected locations.
- Investigate the feasibility of narrowing the yield gap through improvements in crop management strategies.
- Assess the range and effectiveness of adaptation strategies in rain fed agriculture to climate change.
Methods

CROPWAT and AQUACROP, both produced by the Food and Agricultural Organization (FAO), were used to estimate (for present and future climate):
- Crop water use
- Reference evapotranspiration
- Crop yields

Future climate was considered for temperature increase of 1°C, 2°C, and 3°C (corresponding approximately to the year 2025, 2050, and 2080) and rainfall amounts of -10%, +5%, and +10% relative to baseline (current) climate.

A long term temperature increase of 2°C and average precipitation decline of 6% is considered the “worst-case” scenario for the economic analysis; a long-term10% decline is extremely unlikely.
- Required input: daily maximum and minimum air temperatures, rainfall, (ETo), and the mean annual (CO₂) concentration in the atmosphere.

- Simulates **attainable** crop biomass and **harvestable yield** in response to water available (therefore may overestimate relative to actual).

- Application: to compare attainable against actual yields to identify the constraints limiting crop production, serving as a benchmarking tool.

- Pests and diseases are not considered
Methods

Due to lack of credible estimates about their expected future values under climate change, the following variables were not modified: humidity, wind speed, hours of sunshine, and solar radiation.

Climate data obtained from the FAO CLIMWAT (2.0) database available at [www.fao.org/nr/water/infores_databases_climwat.html](http://www.fao.org/nr/water/infores_databases_climwat.html).

Crops analyzed include sorghum, millet, and cowpea. Analysis of maize and rice is ongoing.

All crop data, including crop coefficients (initial, development, mid-season, and late season phases), crop root parameters, and sowing and harvesting dates are obtained from the AQUACROP database.
Dori-Sorghum

**Graph 1:**
- Equation: \( y = 2.7493x - 17 \)
- \( R^2 = 0.9778 \)

**Graph 2:**
- Equation: \( y = -6.7143x - 2.0607 \)
- \( R^2 = 0.933 \)
Sorghum at Dori
Dori-Millet

$y = 2.2321x - 12.216$
$R^2 = 0.9427$

Millet Yield ($\Delta\%$)

$y = -6.8302x - 3.0604$
$R^2 = 0.9861$
y = 1.6817x - 18.657  
$R^2 = 0.9724$

y = 2.0278x - 11.875  
$R^2 = 0.9305$

y = 2.8427x - 5.9885  
$R^2 = 0.7231$

T=+3 C

T=+2 C

T=+1 C

Linear (T=+3 C)

Linear (T=+2 C)

Linear (T=+1 C)
Preliminary conclusions

These results suggest that:

- a +1% change in PCP leads to a +3% change in yield.
- +1°C change in temp leads to between -6% and -8% change in yield.

Questions:

- How do the above rates of change compare to historical periods of rainfall variability?
- What are the corresponding rates of yield changes in other ecological zones and crops?
- What is the effect on yields of simultaneously varying temperature and precipitation?
- How do other factors, such as planting and harvesting dates, soil nutrient management, mulching etc, impact crop yields and what is their utility as climate change adaptation measures?
Increasing yields despite decreasing rainfall


Management more important than climate change???

Source: FAOSTATS, 2012
Crop Yield Elasticity

Proportionate change in yield due to changes in temperature and precipitation.

Log-Linear Y-P-T model:

\[ Y = e^{a \cdot P^b \cdot T^c}, \]

or in the log-linear domain:

\[ \ln (Y) = a + b \ln (P) + c \ln (T) \]

Y=yield

P=precipitation

T=Temperature
The parameters $b$ and $c$ (shape factors) could be obtained from (see Pike and Turkey, 1954)

\[
\frac{(Q-\mu_Q)}{\mu_Q} = b \frac{(P-\mu_P)}{\mu_P} + c \frac{(T-\mu_T)}{\mu_T}
\]

\[
b = \varepsilon_P = \left(\frac{C_v_Q}{C_v_P}\right) \left[\frac{(\rho_{QP} - \rho_{PT}\rho_{QT})}{(1-\rho_{PT}^2)}\right]
\]

\[
c = \varepsilon_T = \left(\frac{C_v_Q}{C_v_T}\right) \left[\frac{(\rho_{QT} - \rho_{PT}\rho_{QP})}{(1-\rho_{PT}^2)}\right]
\]

\[
a = \mu_Q / \left[\Sigma P^b/n\right] = \text{scale factor}
\]
Relationships among the three crop variables
\[ y = 0.6282e^{0.547x} \]

\[ R^2 = 0.9104 \]
Preliminary findings

- A +1% change in PCP leads to a +3% change in yield.

- +1°C change in temp leads to between -6% and -8% change in yield.

- The method allows us to establish the Yield sensitivity to precipitation and temperature change but more analysis is needed to be definitive.

- Historical patterns suggest that field management options may be more important than climate change at least within narrow ranges.

- The method appears feasible as a first pass approach to estimating the impacts of climate change on crop yields.
Thank You!