Impact of Climate Change and Climate Variability on Productivity of Grain Crops

P.V. Vara Prasad
Associate Professor – Crop Physiology
Department of Agronomy, Kansas State University
E-mail: vara@ksu.edu
1. Climate change and climate variability (past and future).

2. Temperature and carbon dioxide: response of grain sorghum and dry bean.

3. Climate change and variability in El Salvador (climate models).

4. Impact of temperature increase on grain yield of sorghum, maize and dry bean in El Salvador (crop simulation models).

5. Concluding remarks.
Part I: Climate Change and Climate Variability
## Past, Current and Future Population

*World: Current Population (20 April 2011): 6,913,282,002*


---

**World Population**

<table>
<thead>
<tr>
<th>Year</th>
<th>Population in Billions</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>2</td>
</tr>
<tr>
<td>1500</td>
<td>4</td>
</tr>
<tr>
<td>2000</td>
<td>6</td>
</tr>
<tr>
<td>2500</td>
<td>10</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2550</td>
<td>12</td>
</tr>
<tr>
<td>3000</td>
<td>14</td>
</tr>
</tbody>
</table>

---

*World population is continuing to increase dramatically.*
Concentrations of CO₂, CH₄, N₂O and SO₄ have dramatically increased in the recent years since 1950.
Surface air temperatures increased on average by 0.75°C. The world has warmed up!

Annual temperature have changed rapidly in recent years.
Annual Precipitation Trends (1901-2005)

Annual precipitation slightly changed and has become variable.
El Salvador’s population will increase by about 30% by 2050.
Models predict air temperatures to increase by 1.4 to 5.8°C. Global average in 2085 relative to 1990 = 3.1°C. El Salvador also in the same ranges.
Models predict annual precipitation increase, but more dry spells. Annual mean precipitation in relative to 1990. El Salvador will see more dry spells and drought events.
Part II: Impact of Climate Change – Temperature and Carbon Dioxide
Grain Sorghum and Dry Bean
Effects of high CO\textsubscript{2} on photosynthesis and growth are mostly beneficial and are widely investigated.

Effects of high (above optimum) temperature on growth, reproductive processes and yields are poorly understood.

Interactions of high temperature and CO\textsubscript{2} on reproductive process and yield are not well understood.
Soil Plant Atmospheric Research (SPAR) Growth Chambers

Naturally sunlit chambers (8 chambers) at University of Florida. Accurate control of air temperature, dew point temperature and carbon dioxide.
Experimental Evidence: Grain Sorghum Season Long High Temperature Stress
Eight Treatments

Temperatures (4):
32/22, 36/26, 40/30 and 44/34 °C
controlled in sinusoidal wave fashion
(daytime maximum/nighttime minimum)

Carbon dioxide (2):
Ambient (350 µmol CO₂ mol⁻¹)
Elevated (700 µmol CO₂ mol⁻¹)

Cultivar / Hybrid: Dekalb 28E

Population: 20 plants m⁻²
High temperature stress inhibited panicle emergence.

Grain Sorghum: Panicle Emergence

A = 32/22 °C
B = 36/26°C
C = 40/30°C
D = 44/34°C

Elevated temperatures decreased % seed-set.
Elevated CO₂ decreased seed-set.

Elevated temperatures decreased seed yield.
Elevated CO\textsubscript{2} increased yields at 32/22 °C, but not at high temperatures (36/26; or 40/30 °C)

Short Term High Temperature Stress
High temperature stress (10 days) decreased seed-set and seed yield.
High temperature stress for 10 d at 10 d before panicle emergence decreased pollen starch content and pollen viability.
Genetic Variability: Opportunities for High Temperature Tolerance in Sorghum
Influence of short episodes (10 d) of high temperature stress starting 10 d prior to flowering on pollen germination

<table>
<thead>
<tr>
<th>Genotype / Hybrid</th>
<th>Optimum Temperature (OT) (32/22°C)</th>
<th>High Temperature (HT) (38/28°C)</th>
<th>% Decrease from OT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK-28-E</td>
<td>86</td>
<td>18</td>
<td>79&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>DKS-29-28</td>
<td>75</td>
<td>25</td>
<td>67&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>DK-54-00</td>
<td>72</td>
<td>42</td>
<td>42&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pioneer 84G62</td>
<td>80</td>
<td>38</td>
<td>52&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Hybrids varied in response to high temperature for pollen germination.
## High Temperature Stress: Genotypic Differences

Influence of short episodes (10 d) of high temperature stress starting 10 d prior to flowering on seed-set

<table>
<thead>
<tr>
<th>Genotype / Hybrid</th>
<th>Optimum Temperature (OT)</th>
<th>High Temperature (HT)</th>
<th>% Decrease from OT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(32/22°C)</td>
<td>(38/28°C)</td>
<td></td>
</tr>
<tr>
<td>DK-28-E</td>
<td>92</td>
<td>25</td>
<td>73&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>DKS-29-28</td>
<td>82</td>
<td>34</td>
<td>55&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>DK-54-00</td>
<td>52</td>
<td>53</td>
<td>42&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pioneer 84G62</td>
<td>55</td>
<td>55</td>
<td>40&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Hybrids varied in response to high temperature for seed-set percentage.
Experimental Evidence: Dry Bean Season Long Temperature Stress
Dry Bean (Red Kidney Type)

Eight Treatments

Temperatures (3 or 5):

- 28/18, 34/24, and 40/30 °C at Ambient CO₂
- 28/18, 31/21, 34/24, 37/27 and 40/30 °C at Elevated CO₂

controlled in sinusoidal wave fashion
(daytime maximum/nighttime minimum)

Carbon dioxide (2):

- Ambient (350 µmol CO₂ mol⁻¹)
- Elevated (700 µmol CO₂ mol⁻¹)

Cultivar: Montcalm

Population: 24 plants m⁻²
Temperatures $> 28/18^\circ C$ decreased seed-set. Elevated CO$_2$ also decreased seed-set.

Dry Bean: Seed Number and Seed Size

Temperatures > 28/18°C decreased seed number and seed size. Elevated CO$_2$ did not influence seed number or seed size.

Dry Bean: Biomass and Seed Yield

Temperatures > 28/18°C decreased biomass.
Elevated CO₂ increased biomass.
Benefits of elevated CO₂ decreased with increasing temperatures.

Season long elevated temperatures decreased harvest index due to lower seed yields caused by decreased seed-set.


A general rule of thumb is that there will be a 10% decrease in yield for every 1 degree centigrade rise in temperature above optimum temperature for reproductive growth for that crop.
Conclusions

- High temperature stress decreased grain yield.
- There were no beneficial effects of elevated CO$_2$ on pollen viability or seed-set.
- Beneficial effects of elevated CO$_2$ on seed yield decreased with increasing temperatures.
- Negative effects of high temperatures on seed-set and harvest index were greater at elevated CO$_2$. 
Response of Crops to Drought Stress
Grain yield is proportional to water use for most grain crops.

Source: Dr. L.R. Stone
Kansas State University
Reproductive stages are relatively more sensitive to drought stress. Drought decreased kernel number and dry weights.

Part III: Climate Change and Variability in El Salvador
(General Circulation Models and Emission Scenarios)
There are two General Circulation Models (3 sites) for El Salvador.
Crop Simulation and Climate Model: Methods

- Crop modeling was performed in DSSAT (Decision Support System for Agrotechnology Transfer) software suite.
- CERES-Sorghum and CERES-Maize and CROPGRO-Dry bean were used to simulate phenology and grain yield.
- Two Global climate models (GCM) used in this study were Canadian GCM (CGCM3.1 T47) and Australian GCM (CSIRO-Mk3.5)
- Three IPCC-SRES climate scenario (A1B, A2 and B1) data for historic period (1971-2000) and future (2041-2070) were acquired from Program for Climate Model Diagnosis and Intercomparison (PCMDI)
Three scenarios (A1B, A2 and B1) were used for simulations.
There are uncertainties in different models of past data (1970 - 2000) from Acajulta (El Salvador)
El Salvador: Uncertainties in Emission Scenarios: Future: Maximum Temperature

There are uncertainties in different emission scenarios and model predictions. El Salvador will be about 3-5 °C warmer.

There are uncertainties in different emission scenarios and model predictions. El Salvador will be drier in future.
Part IV: El Salvador: Impact of Climate Change (High Temperatures) on Crop Yields (Crop Simulations Models)
El Salvador: Grain Sorghum Model

Grain Sorghum Model (DSSAT Suite)

Soil – Luvic Phaeozem
Cultivar – Local Cultivar
Plant Population – 150,000 plants/ha
Planting Date – May 15
El Salvador: Impact of Climate Change in Grain Sorghum Yield

Models predict yield losses of 5 – 15%, in both eastern and western regions.
El Salvador: Maize Model

Maize Model (DSSAT Suite)

Soil – Luvic Phaeozem
Cultivar – Medium Season Local Cultivar
Plant Population – 150,000 plants/ha
Planting Date – May 15
El Salvador:
Impact of Climate Change on Maize Yield

Models predict yield losses of 3 – 13%, in both eastern and western regions.
El Salvador: Dry Bean Model

Dry Bean (DSSAT Suite)

Soil – Luvic Phaeozem
Cultivar – Landrace cultivar (Rabia de Gato)
Plant Population – 300,000 plants/ha
Planting Date – August 20
El Salvador: Impact of Climate Change on Dry Bean Yield

Models predict yield losses of 25 – 50%, in both eastern and western regions.
Crop Simulation Model: Opportunities

Grain Sorghum

- Crop modeling tests suggested that earlier planting sorghum (April 15 vs. May 15) can improve yields.
- Using longer season genotypes or increasing grain filling duration will improve grain yields.
- Growing high temperature and drought tolerant genotypes is important.

Dry Bean

- Later planting (August vs. September) increased yields.
- Increasing seed filling duration and seed size can increase seed yield.
- High temperature and drought tolerant genotypes will play important role in improving yields.
Concluding Remarks

✓ High temperature stress decrease yield of sorghum, bean and maize.

✓ Reproductive processes of grain sorghum and dry bean are more sensitive to high temperature stress.

✓ GCM predict increases in maximum and minimum temperatures and dry spells for El Salvador. However, there are uncertainties in models and scenarios.

✓ Crop simulation models predicts that in future climates sorghum and maize yields can decrease up to 20%; and dry bean yield up to 50%.

✓ There are opportunities to combat yield losses by adjusting planting dates, selection of genotypes and improving genetics; and other management practices.
“You can’t eat the potential yield, but need to raise the actual by combating the stresses”

Norman E. Borlaug
(Nobel Peace Laureate)

“You cannot build peace on empty stomachs.”

John Boyd Orr
(Nobel Peace Laureate
First FAO Director General)
"We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy."