

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

**P.V. Vara Prasad**

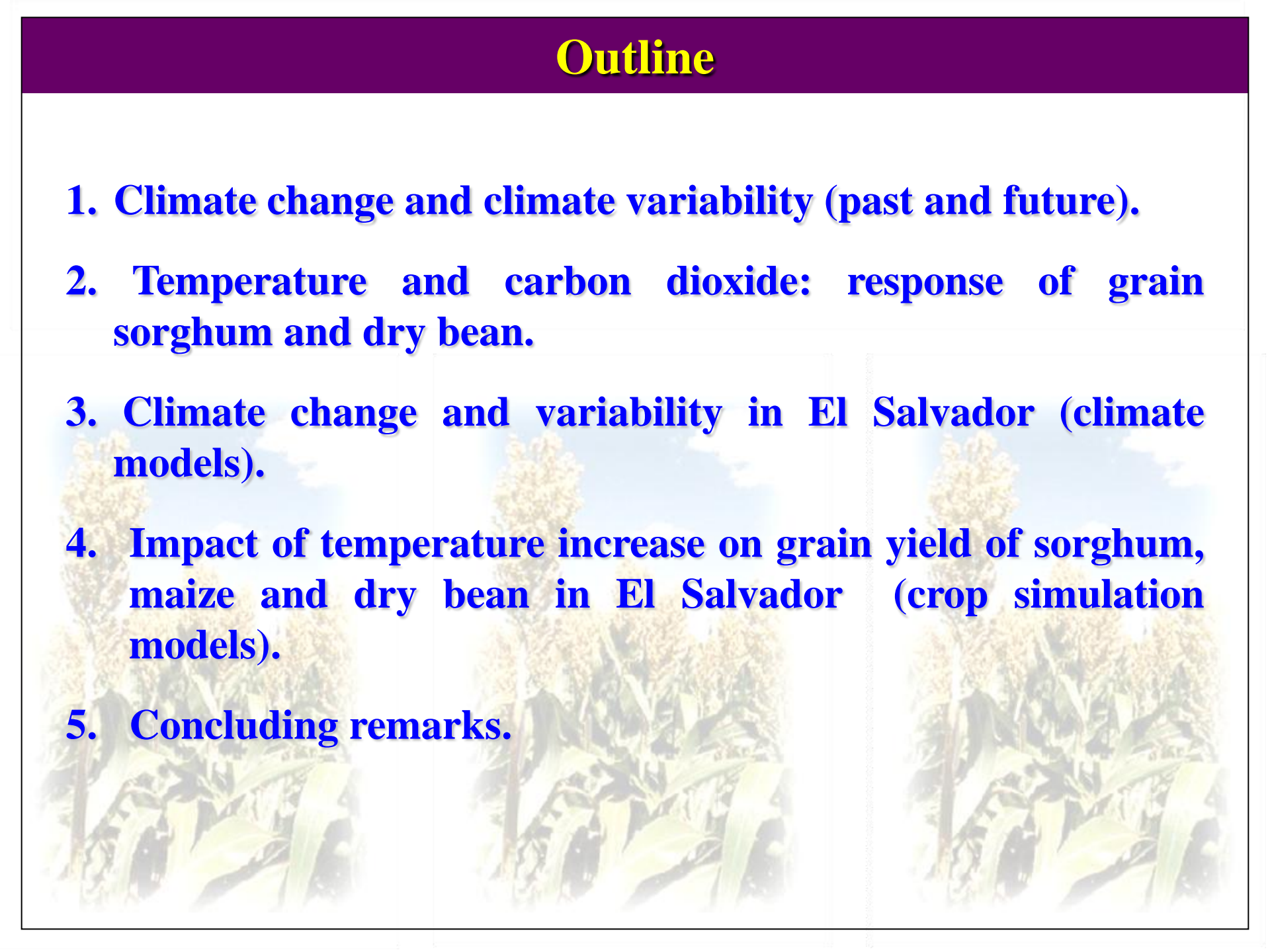
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# Outline

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.**
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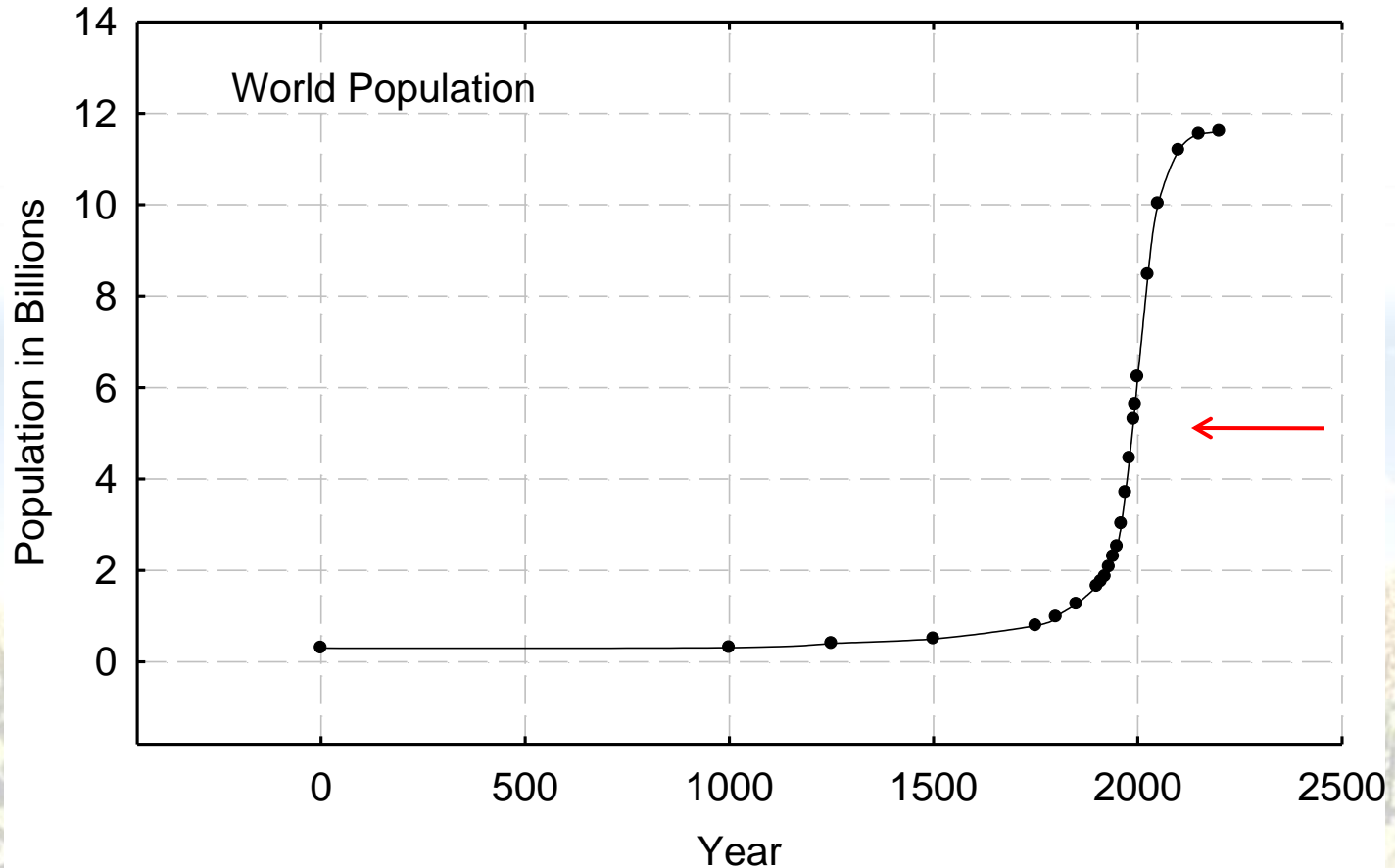
# Part I: Climate Change and Climate Variability



# Past, Current and Future Population

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

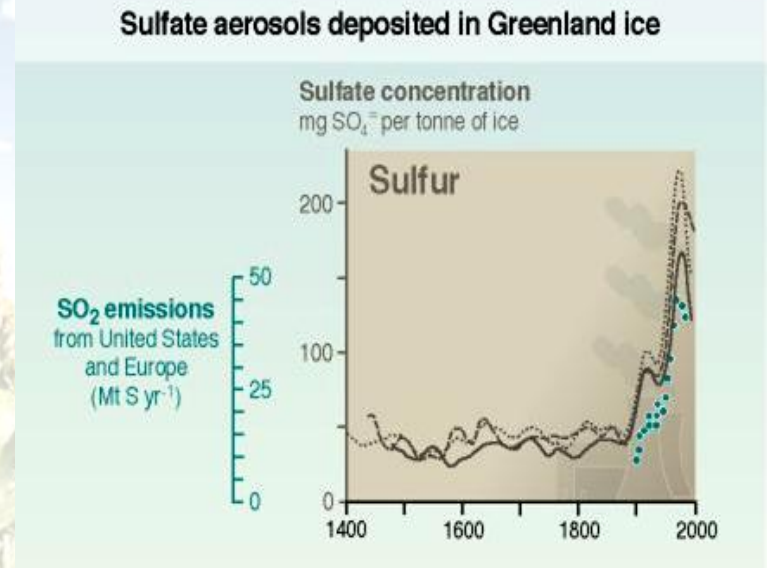
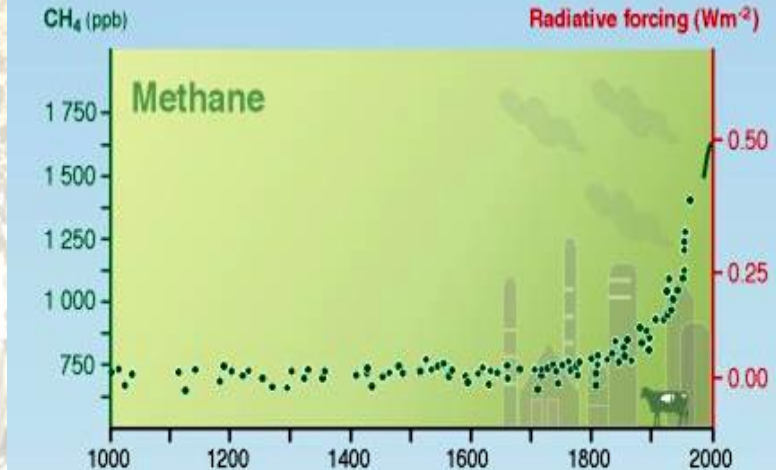
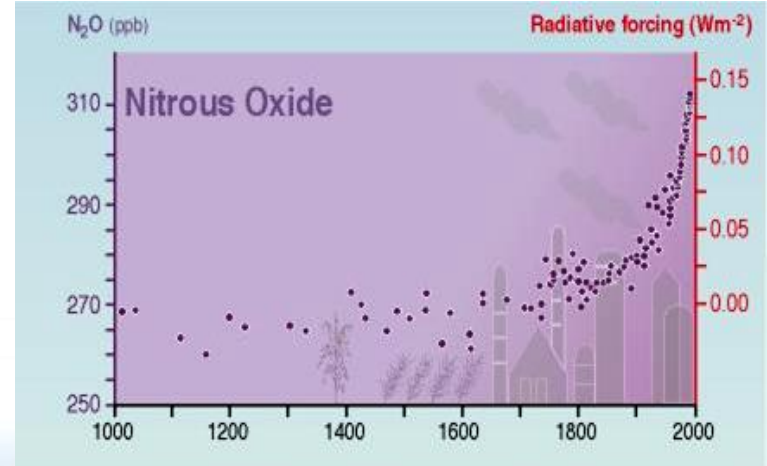
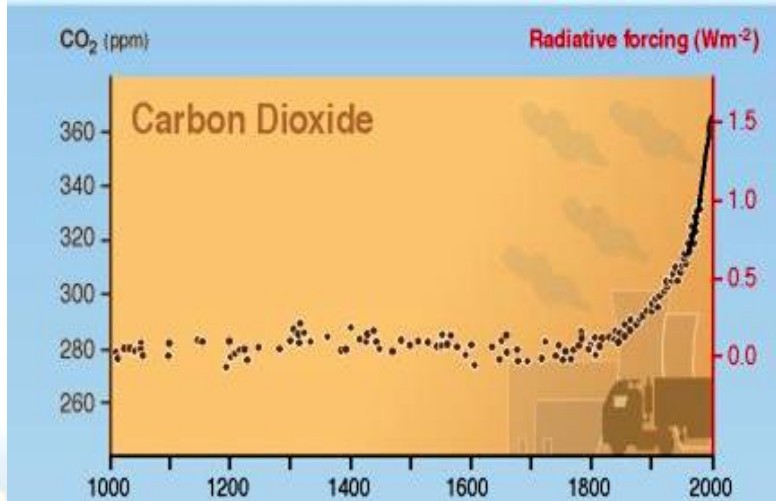
**El Salvador: Current Population (2010): 6,973,500**



**World population is continuing to increase dramatically.**

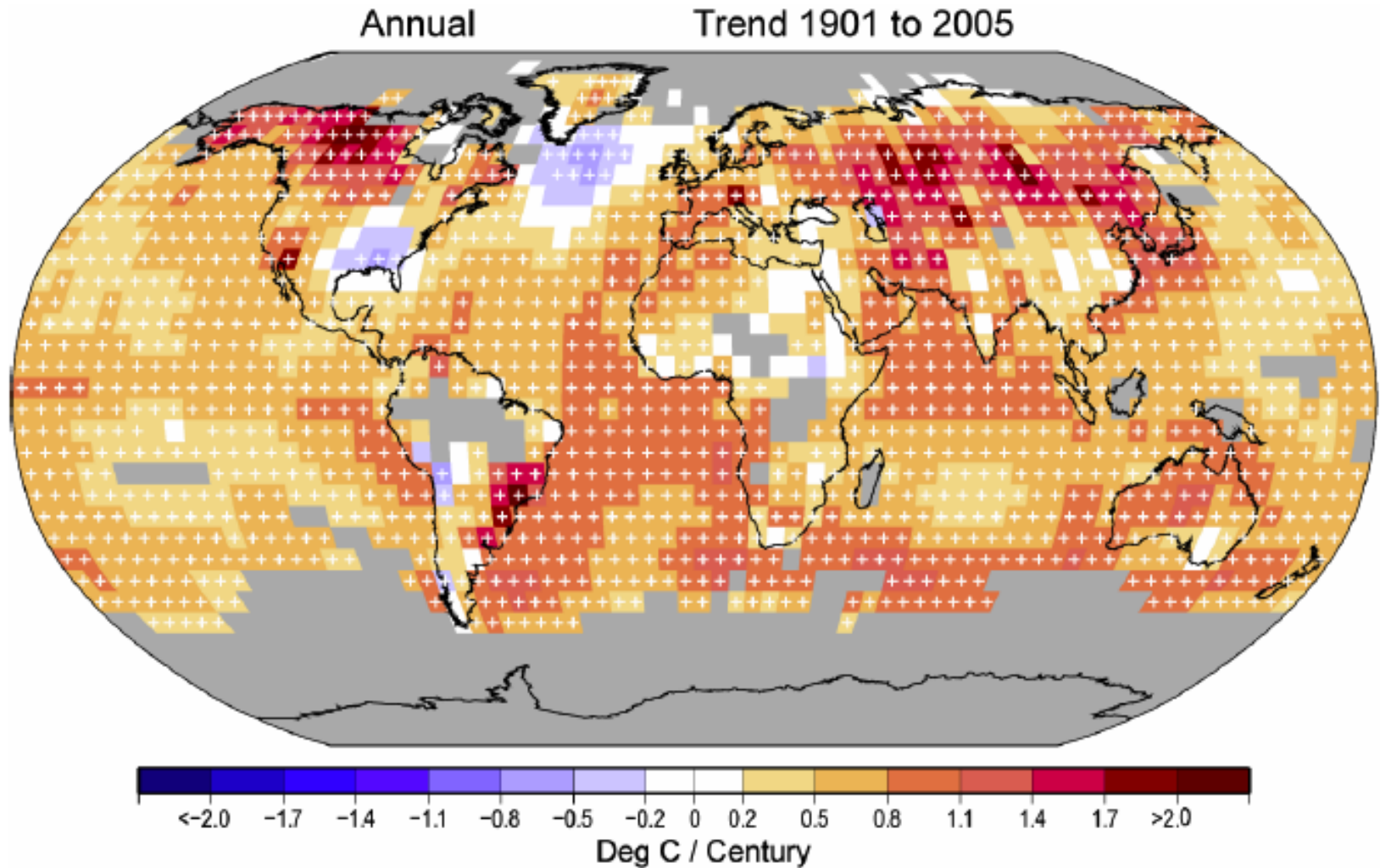


# Greenhouse Gases (Past Changes)



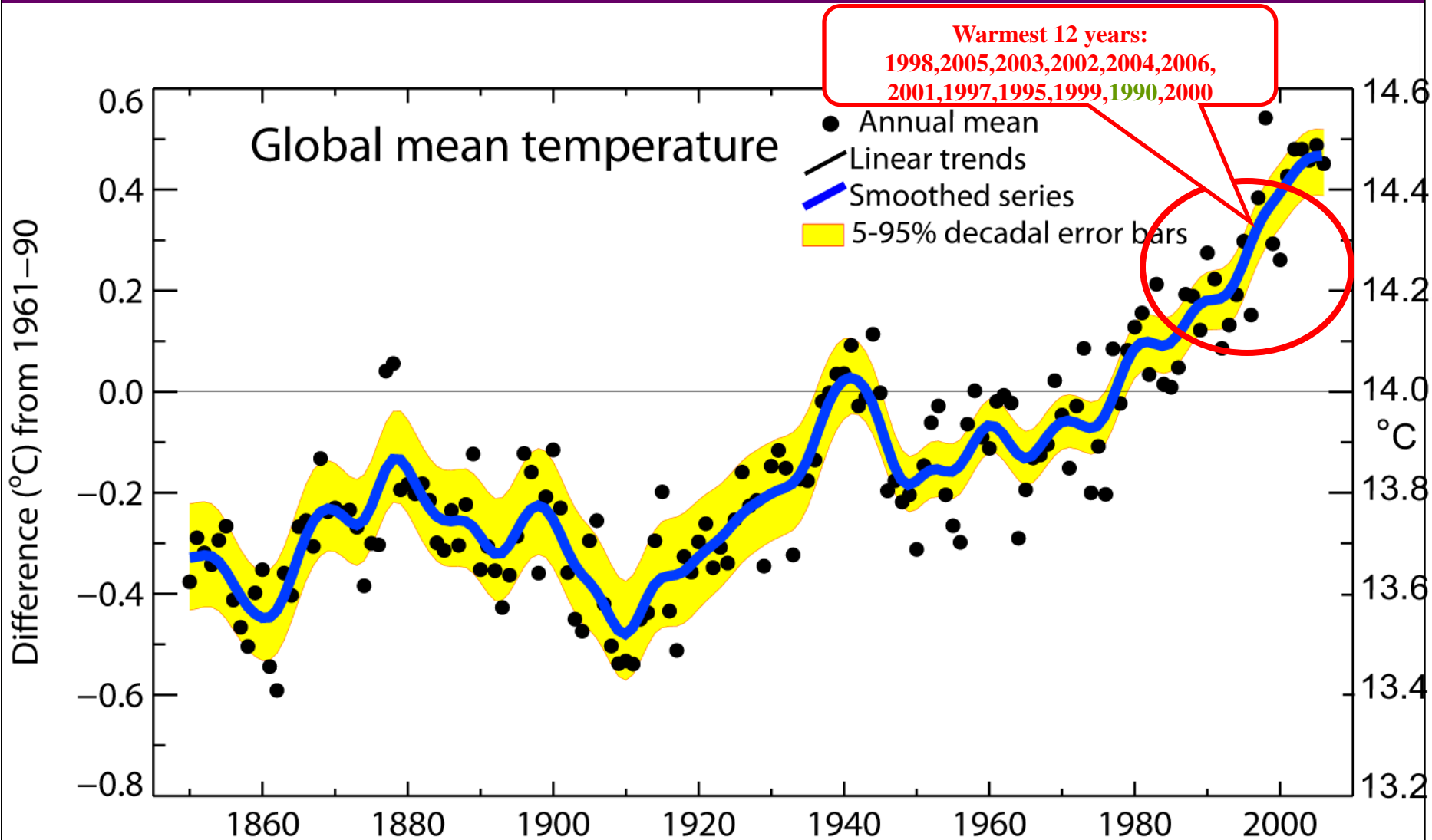
**Concentrations of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and SO<sub>4</sub> have dramatically increased in the recent years since 1950.**

# Annual Temperature Trends (1901-2005)



**Surface air temperatures increased on average by 0.75°C.  
The world has warmed up !**

# Frequency of Warm Years

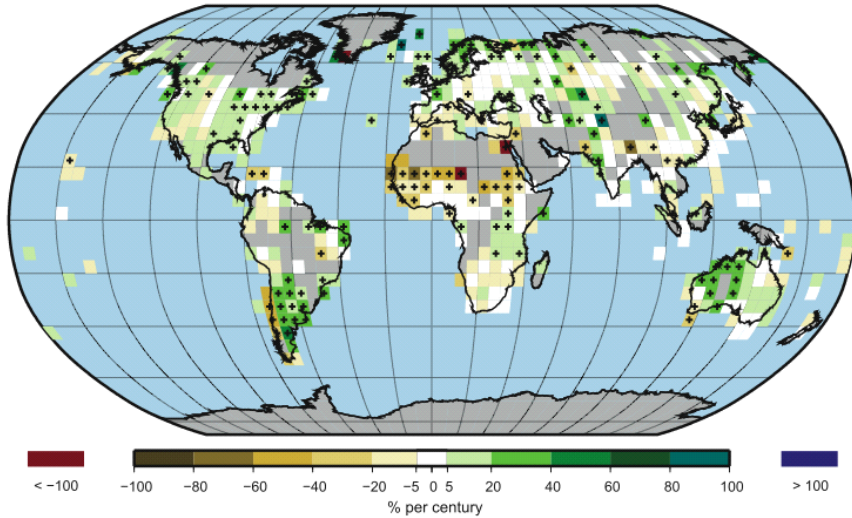


**Annual temperature have changed rapidly in recent years.**

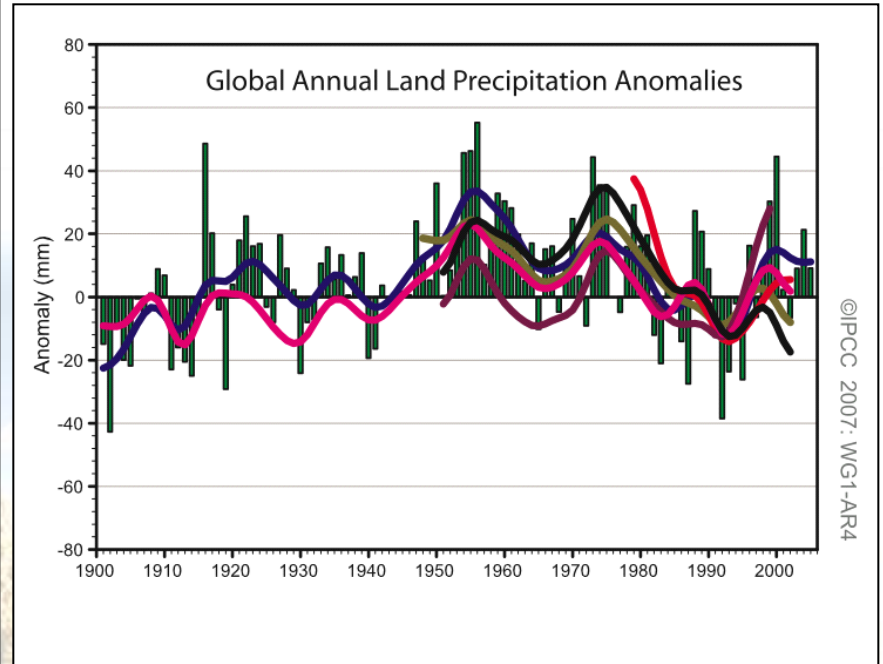
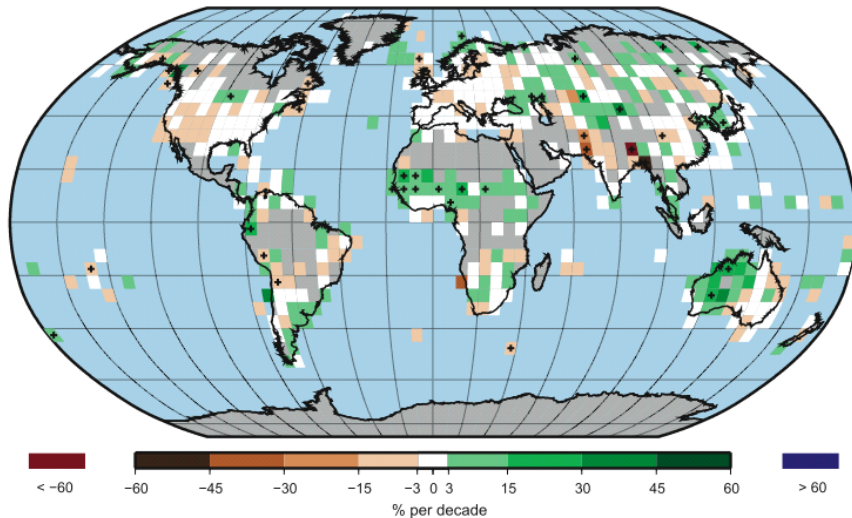


# Annual Precipitation Trends (1901-2005)

Trend in Annual PRCP, 1901 to 2005



Trend in Annual PRCP, 1979 to 2005

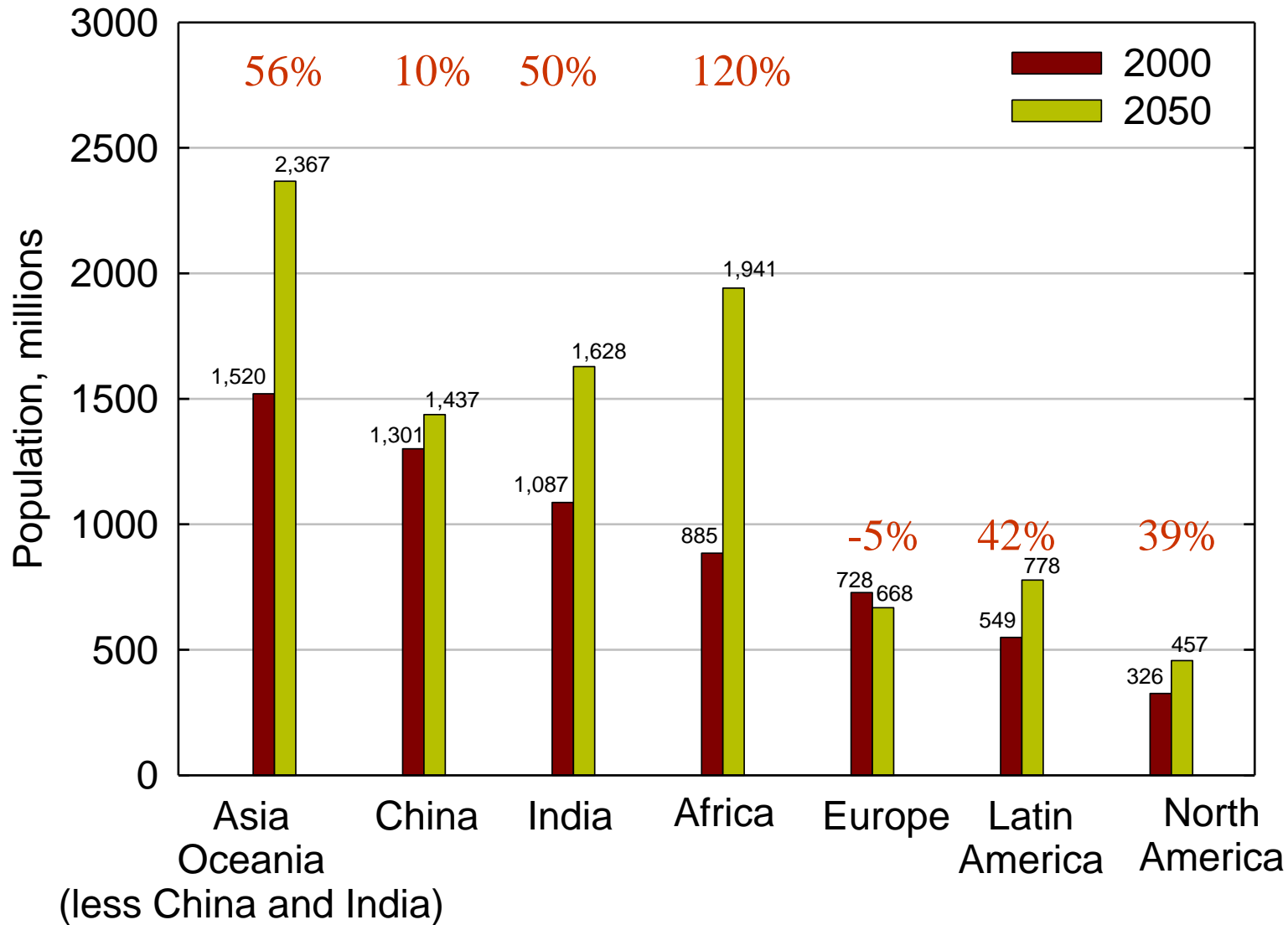


©IPCC 2007: WG1-AR4

**Annual precipitation slightly changed and has become variable.**



# Future Population Growth: Major Countries

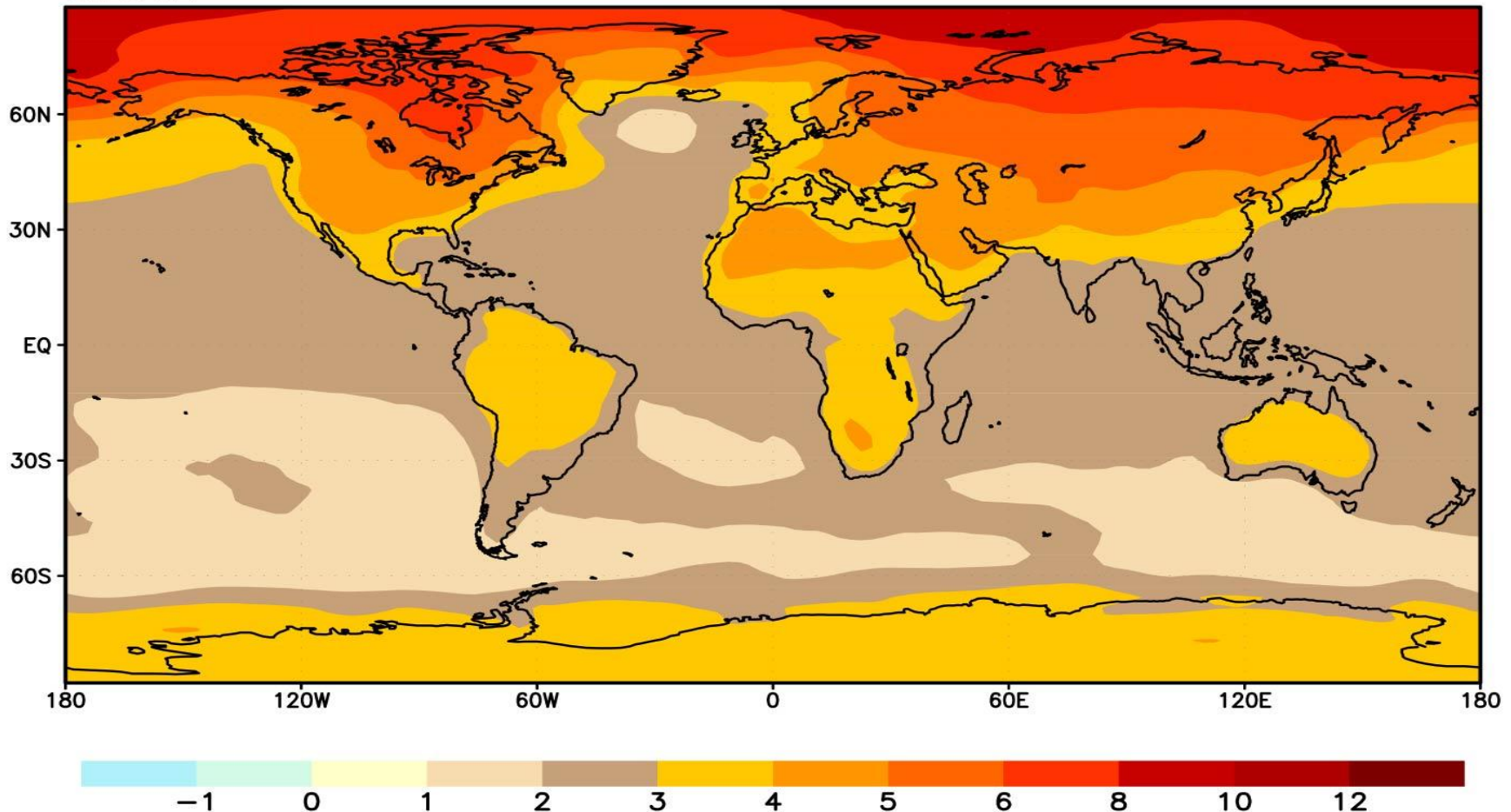


**El Salvador's population will increase by about 30% by 2050.**

# Future Changes in Mean Temperature (2100)

IPCC 2007

SRES A2



**Models predict air temperatures to increase by 1.4 to 5.8°C.**

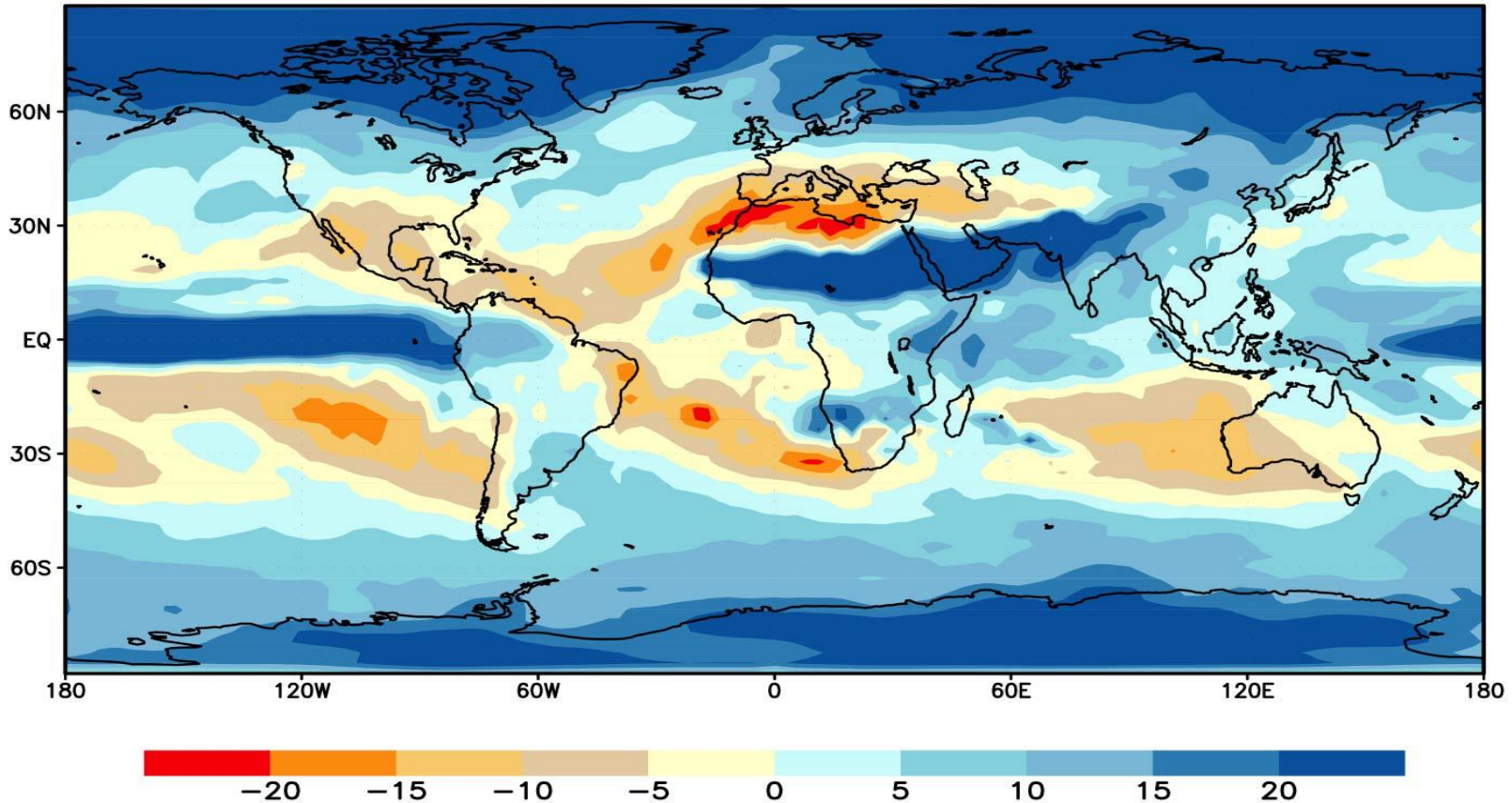
**Global average in 2085 relative to 1990 = 3.1°C.**

**El Salvador also in the same ranges.**

# Future Changes in Annual Precipitation (2100)

IPCC 2007

SRES A2



**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**



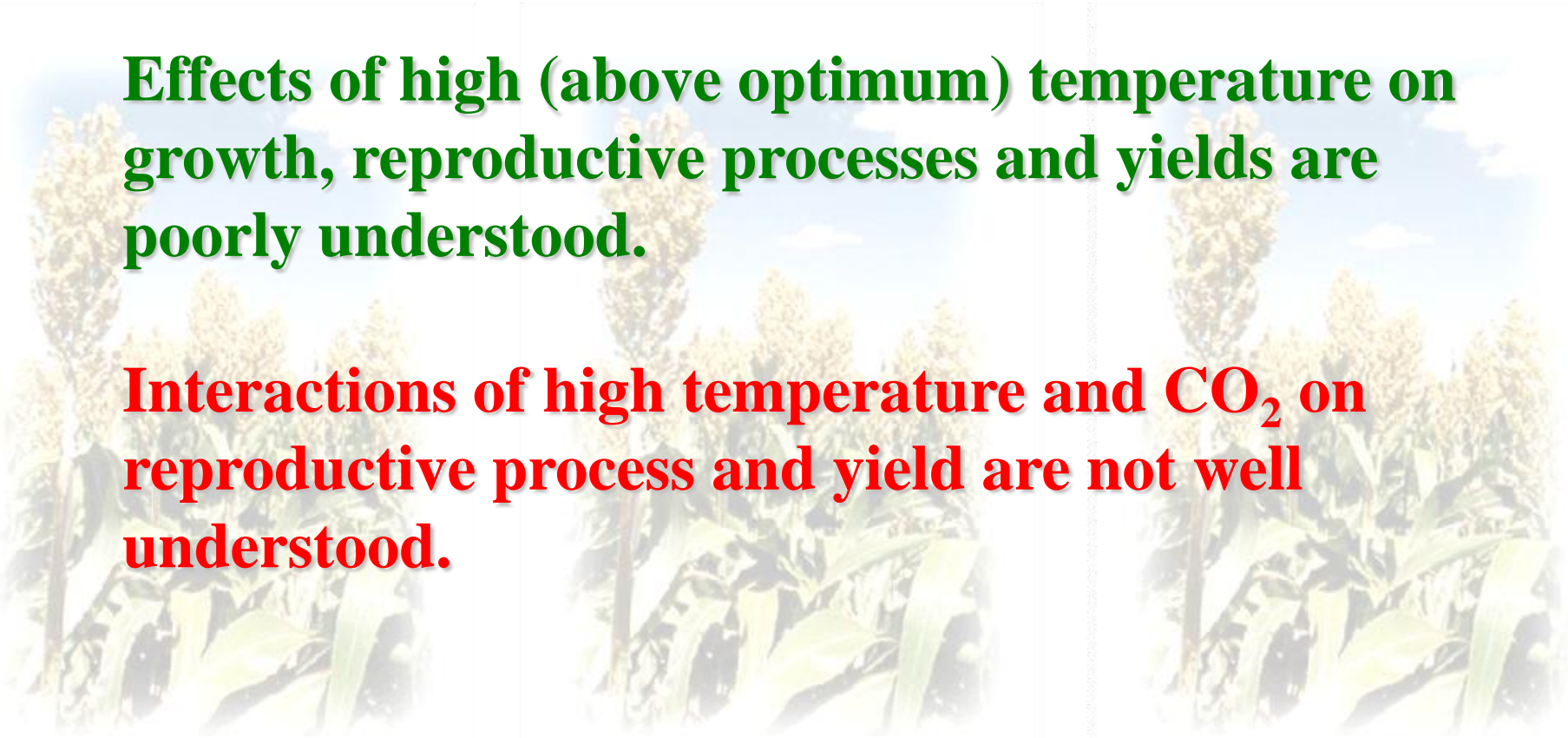


# Effects of High Temperature and CO<sub>2</sub>

**Effects of high CO<sub>2</sub> 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<sub>2</sub> 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**





# Grain Sorghum

## Eight Treatments

### Temperatures (4):

32/22, 36/26, 40/30 and 44/34 C

controlled in sinusoidal wave fashion

(daytime maximum/nighttime minimum)

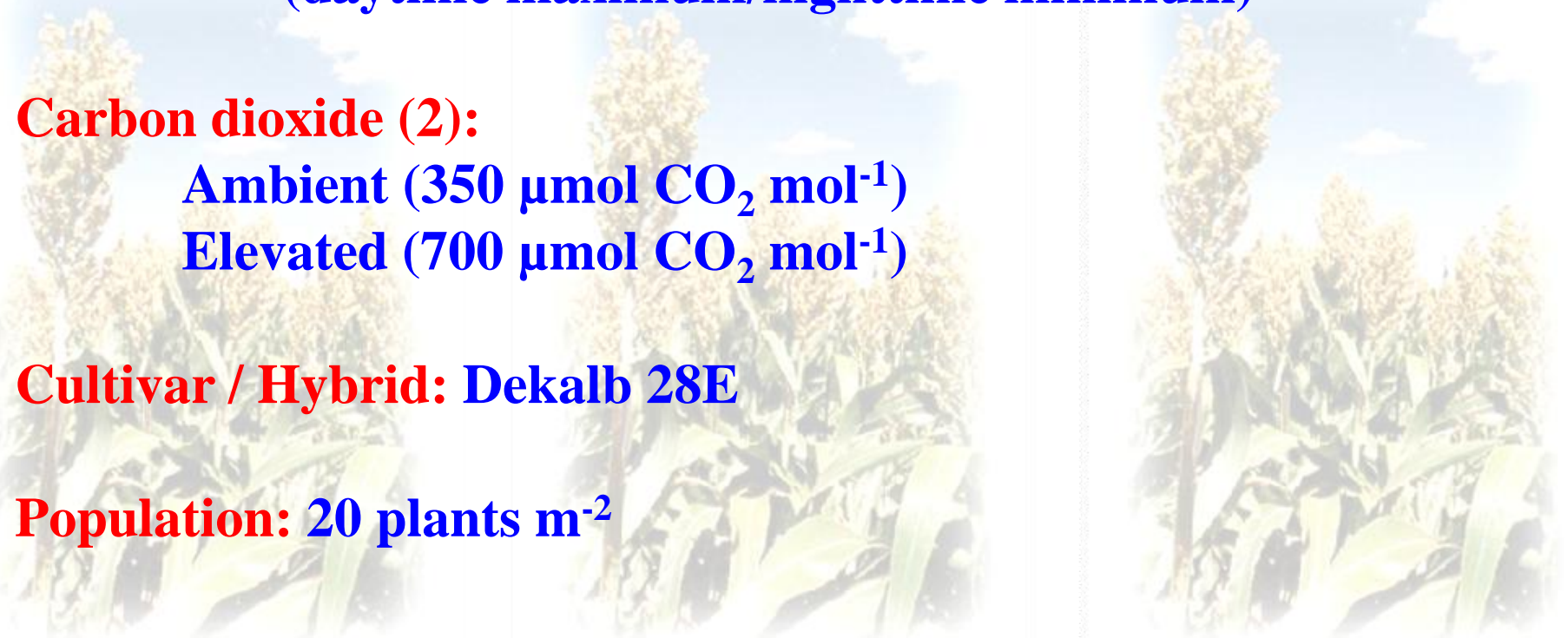
### Carbon dioxide (2):

Ambient ( $350 \mu\text{mol CO}_2 \text{ mol}^{-1}$ )

Elevated ( $700 \mu\text{mol CO}_2 \text{ mol}^{-1}$ )

Cultivar / Hybrid: Dekalb 28E

Population: 20 plants  $\text{m}^{-2}$





# Grain Sorghum: Panicle Emergence

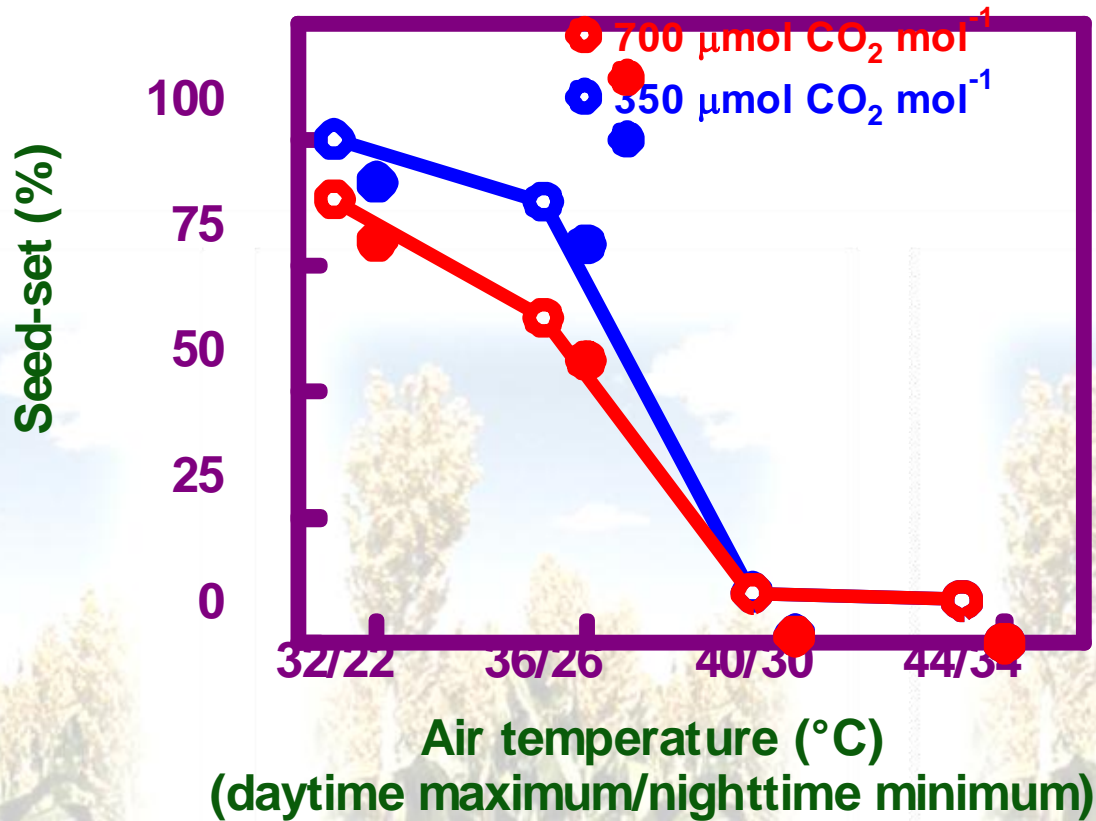


**A = 32/22 C**  
**B = 36/26°C**  
**C = 40/30°C**  
**D = 44/34°C**

Prasad et al., 2006. Agric. For. Meteorol. 139: 237-251.

**High temperature stress inhibited panicle emergence.**

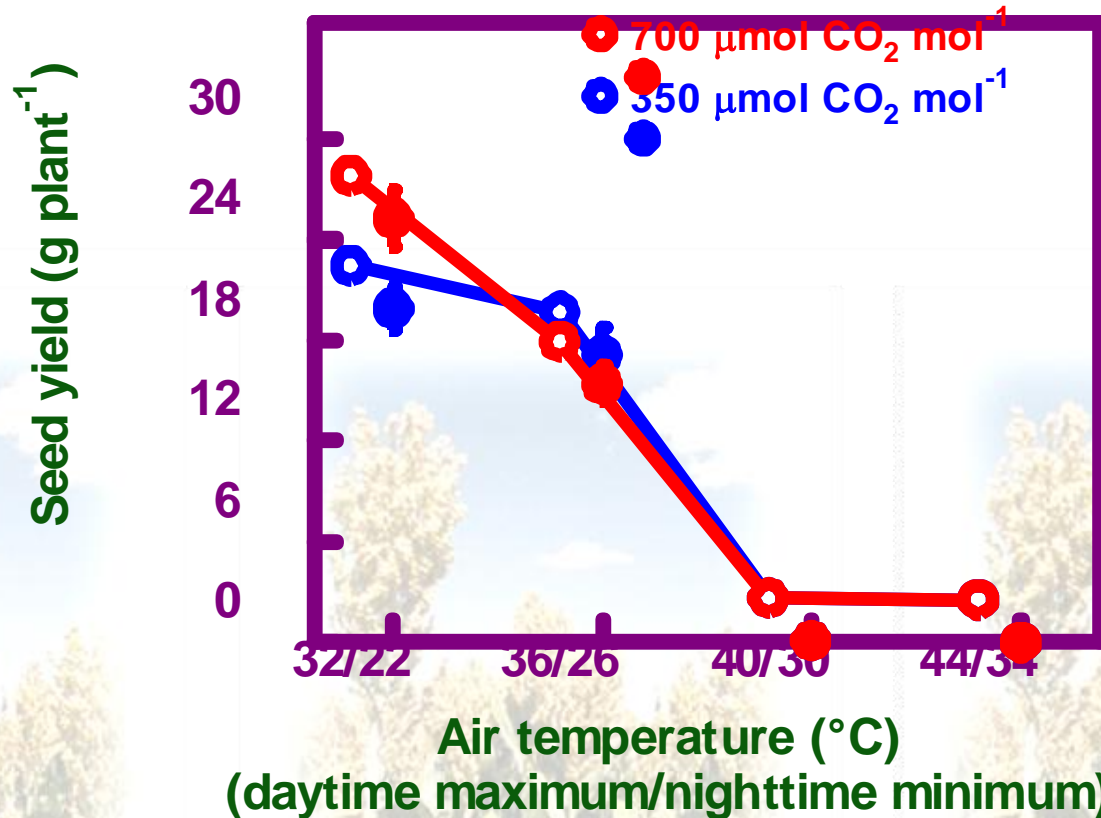
# Grain Sorghum: Seed-Set



Prasad et al., 2006. Agric. For. Meteorol. 139: 237-251.

**Elevated temperatures decreased % seed-set.  
Elevated CO<sub>2</sub> decreased seed-set.**

# Grain Sorghum: Seed Yield



Prasad et al., 2006. Agric. For. Meteorol. 139: 237-251.

**Elevated temperatures decreased seed yield.  
Elevated CO<sub>2</sub> increased yields at 32/22 C,  
but not at high temperatures (36/26; or 40/30 C)**

# Short Term High Temperature Stress





# Short Periods of High Temperature Stress – Sorghum – Seed-set



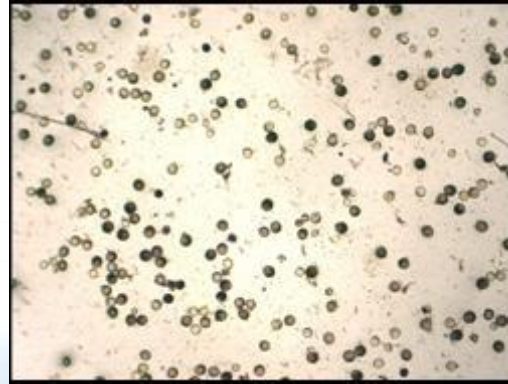
High temperature stress (10 days) decreased seed-set and seed yield.

# Short Periods of High Temperature Stress – Sorghum – Pollen

Control = 32/22 C



36/26 C

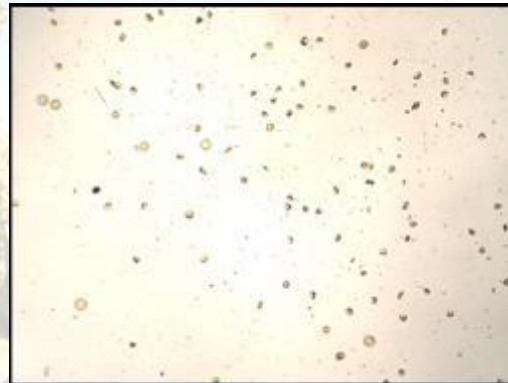


**Duration = 10 days**  
**Stage = 10 d before panicle emergence**

40/30 C



44/34 C



**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



# High Temperature Stress: Genotypic Differences

Influence of short episodes (10 d) of high temperature stress starting 10 d prior to flowering on pollen germination

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

**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

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

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 CO<sub>2</sub>

28/18, 31/21, 34/24, 37/27 and 40/30 C at Elevated CO<sub>2</sub>

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

### Carbon dioxide (2):

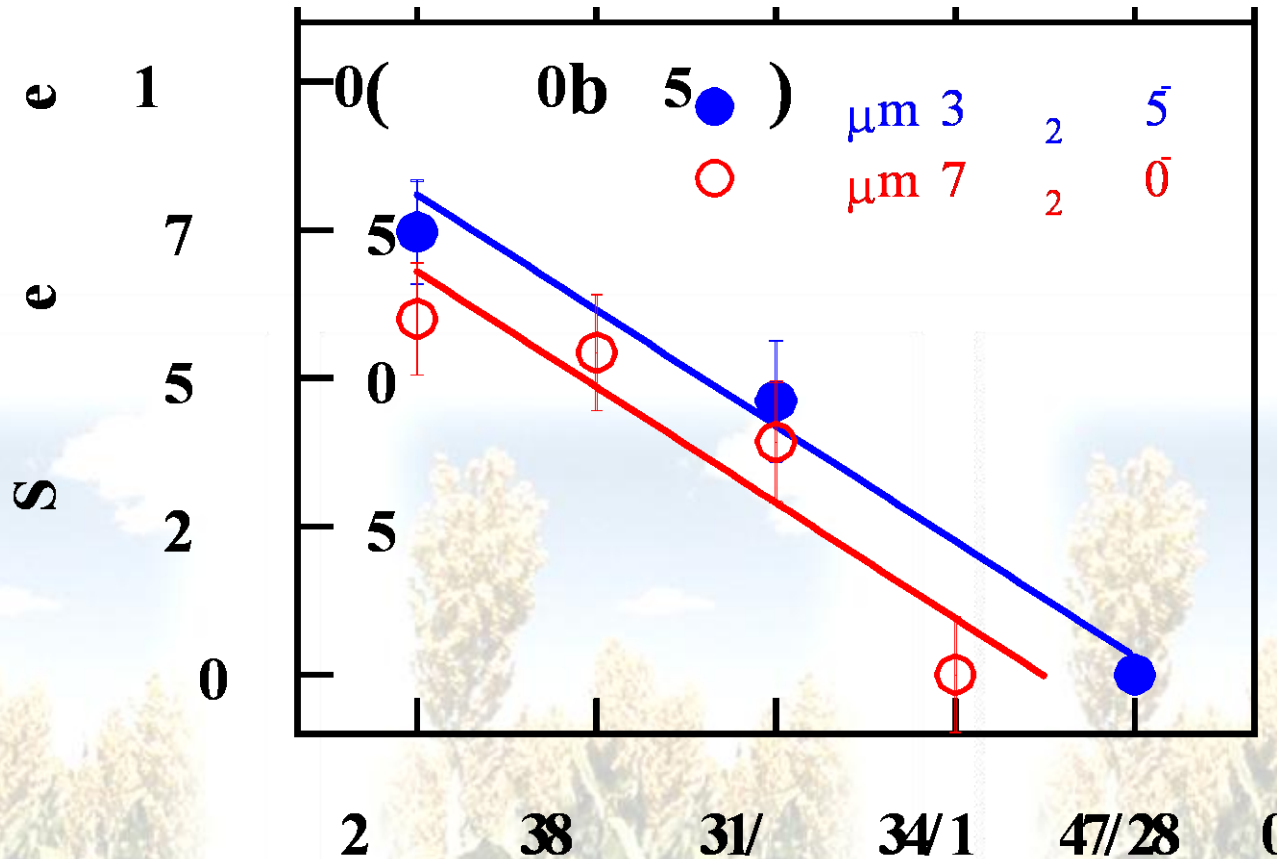
Ambient (350  $\mu\text{mol CO}_2 \text{ mol}^{-1}$ )

Elevated (700  $\mu\text{mol CO}_2 \text{ mol}^{-1}$ )

**Cultivar:** Montcalm

**Population:** 24 plants m<sup>-2</sup>

# Dry Bean: Seed - set

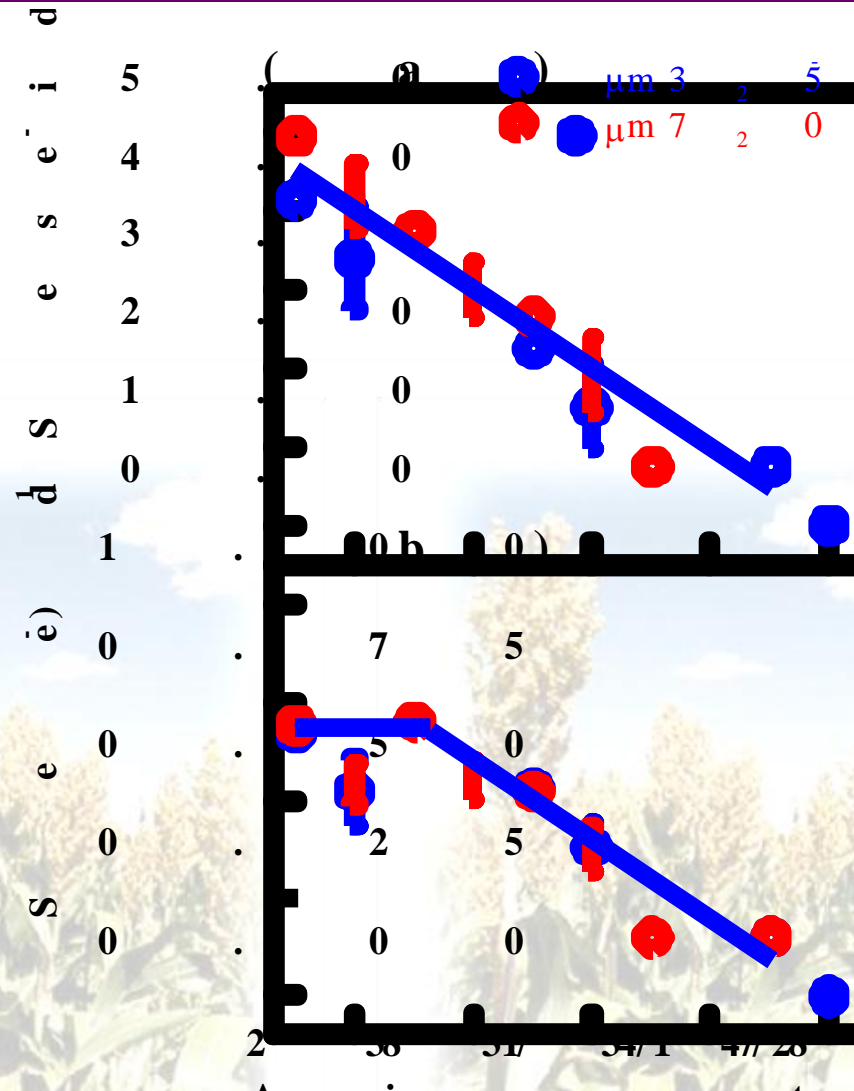


Prasad et al. (2002). Global Change Biol. 8: 710-721.

**Temperatures > 28/18°C decreased seed-set.  
Elevated CO<sub>2</sub> also decreased seed-set.**



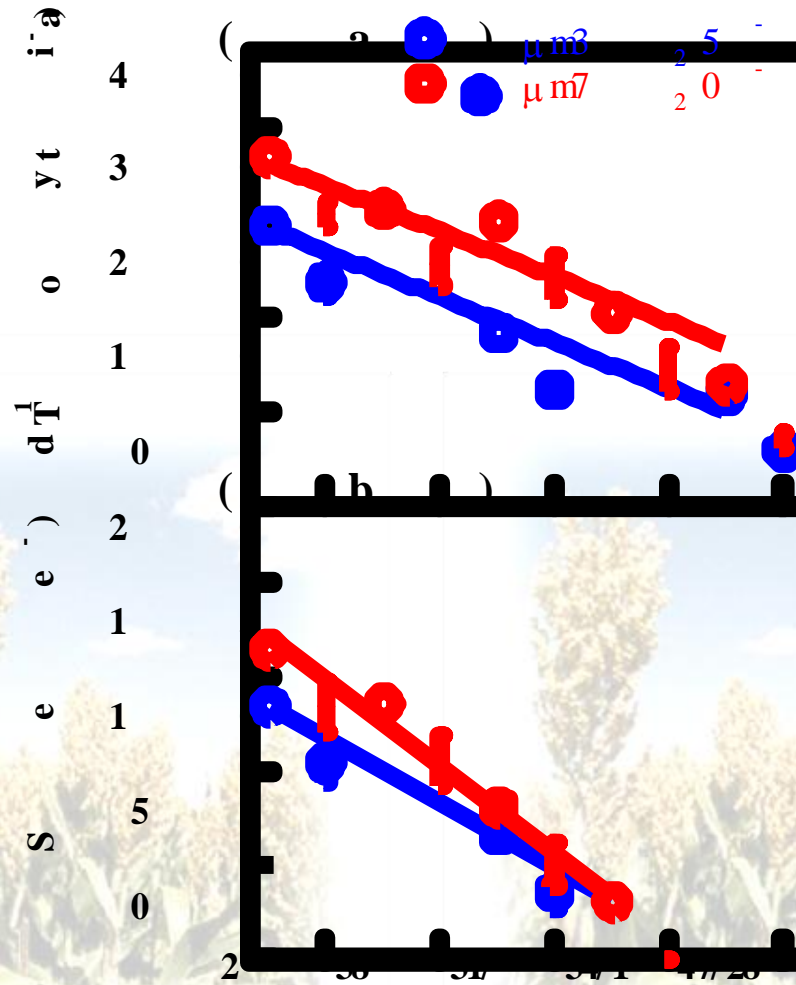
# Dry Bean: Seed Number and Seed Size



Prasad et al. (2002). Global Change Biol. 8: 710-721.

**Temperatures > 28/18°C decreased seed number and seed size.  
Elevated CO<sub>2</sub> did not influence seed number or seed size.**

# Dry Bean: Biomass and Seed Yield



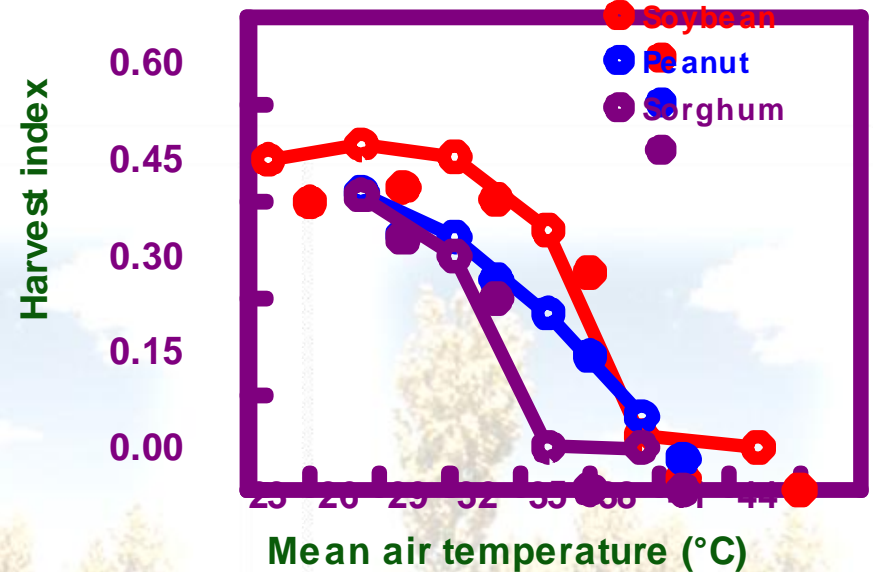
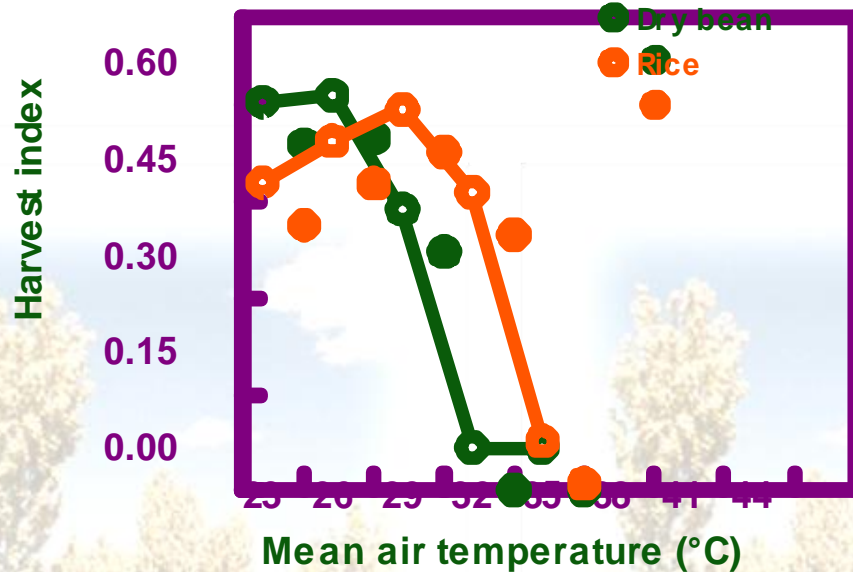
Prasad et al. (2002). Global Change Biol. 8: 710-721.

**Temperatures > 28/18°C decreased biomass.**

**Elevated CO<sub>2</sub> increased biomass.**

**Benefits of elevated CO<sub>2</sub> decreased with increasing temperatures.**

# Sensitivity of Other Crops To Temperature



Daily temperature (day and night)

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

Bean: Prasad et al., 2002. Global Change Biol. 8: 710-721.  
 Peanut: Prasad et al., 2003. Global Change Biol. 9: 1775-1787.  
 Sorghum: Prasad et al., 2006. Agric. For. Meteorol. 139: 237-251.

Rice: Snyder, 2000. MSc Thesis, University of Florida.  
 Soybean: Pan, 1996; Thomas, 2001. PhD Thesis, Univ. Florida.

# Yield Losses: High Temperature Stress

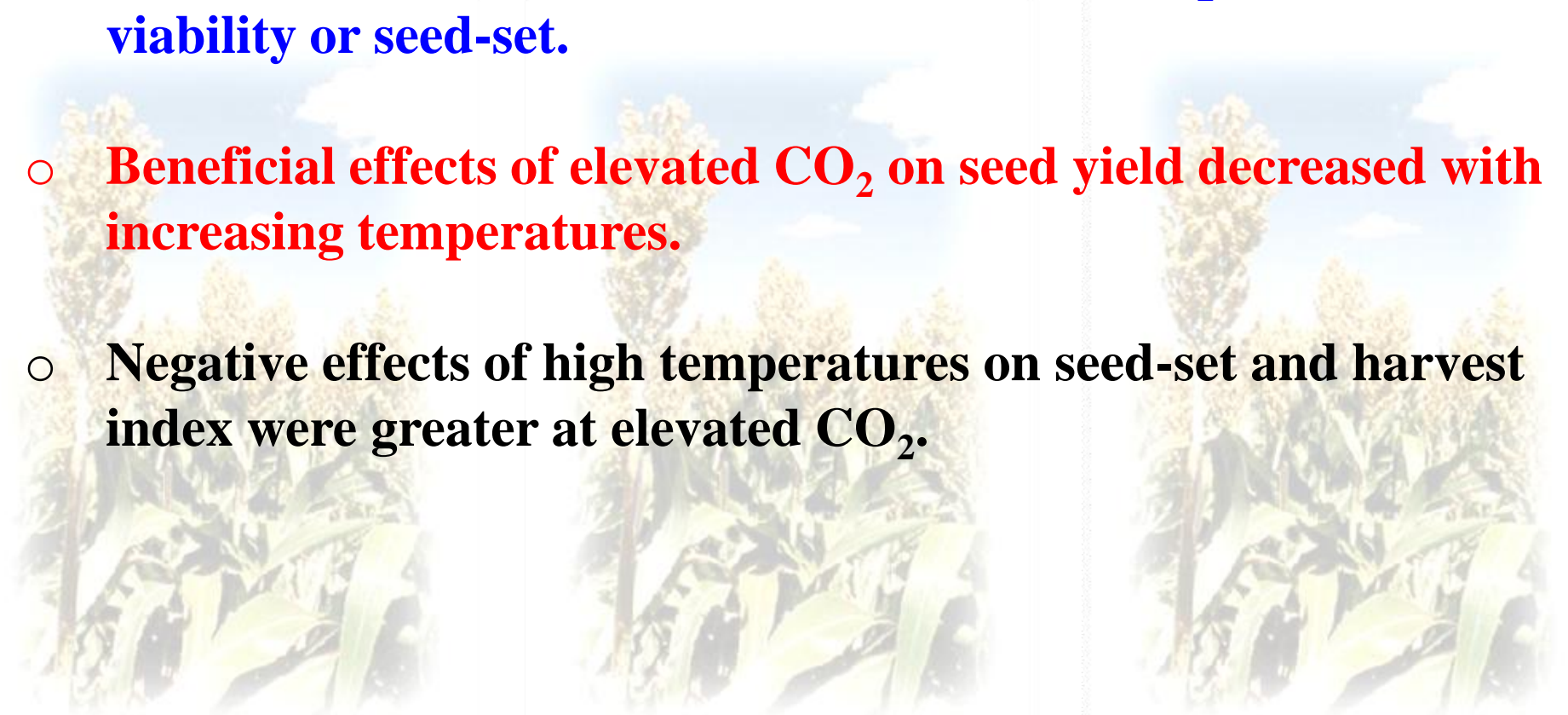
**A general rule of thumb is that there will be a 10% decrease in yield for every 1 degree centigrade rise in temperature above optimum temperature for reproductive growth for that crop.**





# Conclusions

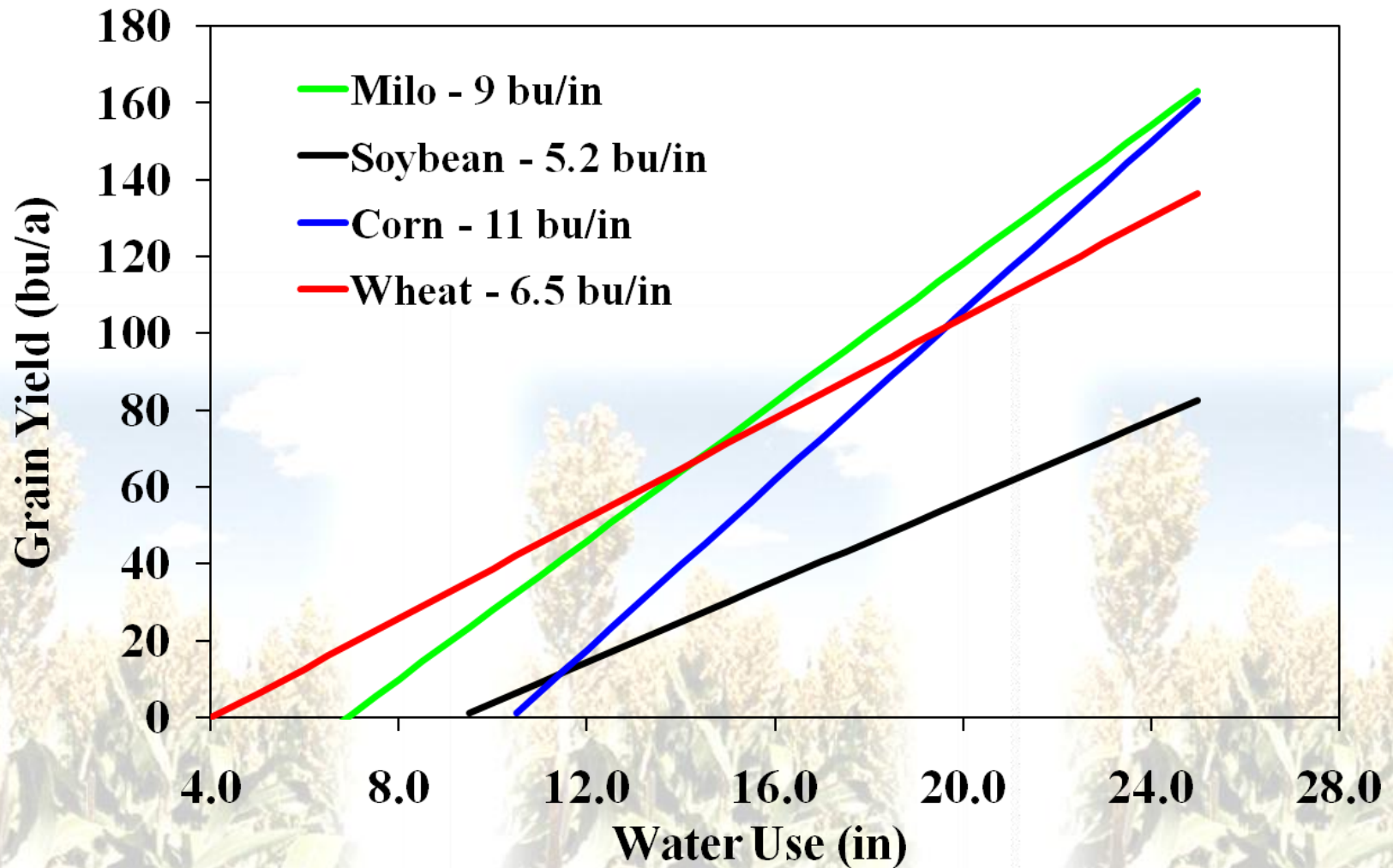
- **High temperature stress decreased grain yield.**
- **There were no beneficial effects of elevated CO<sub>2</sub> on pollen viability or seed-set.**
- **Beneficial effects of elevated CO<sub>2</sub> on seed yield decreased with increasing temperatures.**
- **Negative effects of high temperatures on seed-set and harvest index were greater at elevated CO<sub>2</sub>.**



# Response of Crops to Drought Stress



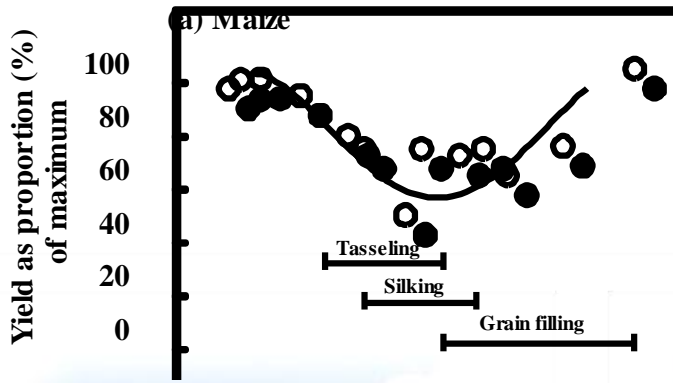
# Crop Responses to Water Use



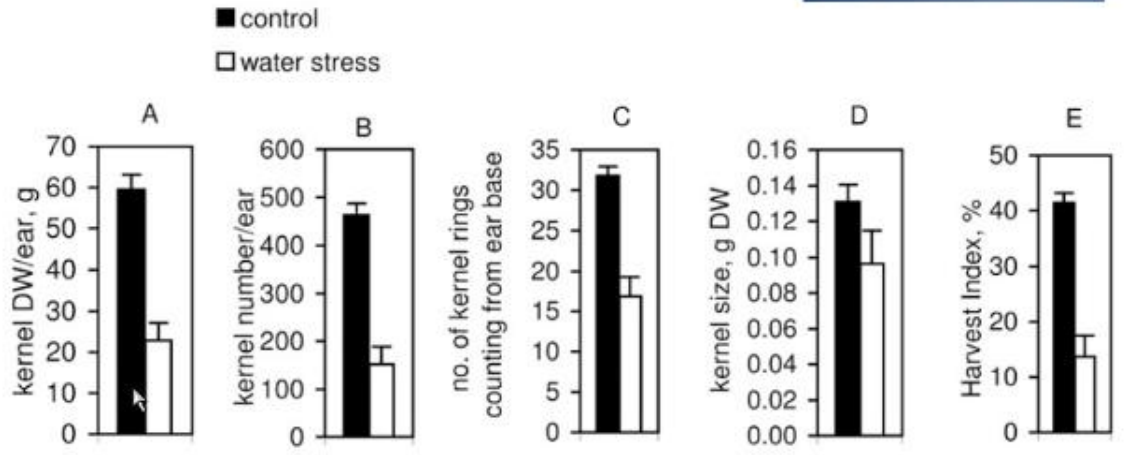
Source: Dr. L.R. Stone  
Kansas State University

**Grain yield is proportional to water use for most grain crops.**

# Maize: Drought Stress on Yield Components



Post-pollination water deficit  
Water stress from 3 to 8 days after pollination



Setter TL, Parra R (2010) Crop Science 50: 980-988

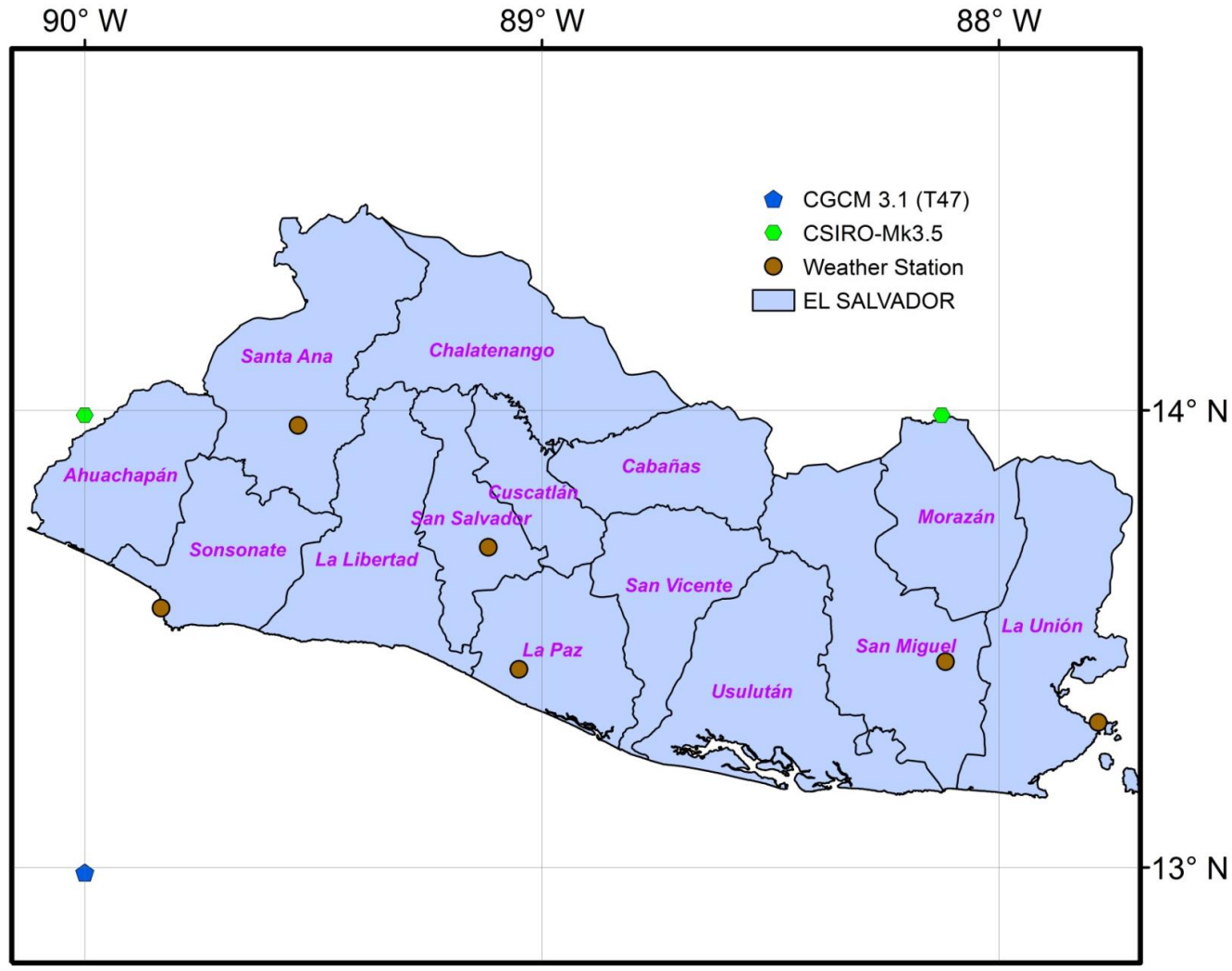
**Reproductive stages are relatively more sensitive to drought stress.  
Drought decreased kernel number and dry weights.**



# **Part III: Climate Change and Variability in El Salvador (General Circulation Models and Emission Scenarios)**



# El Salvador: General Circulation Models

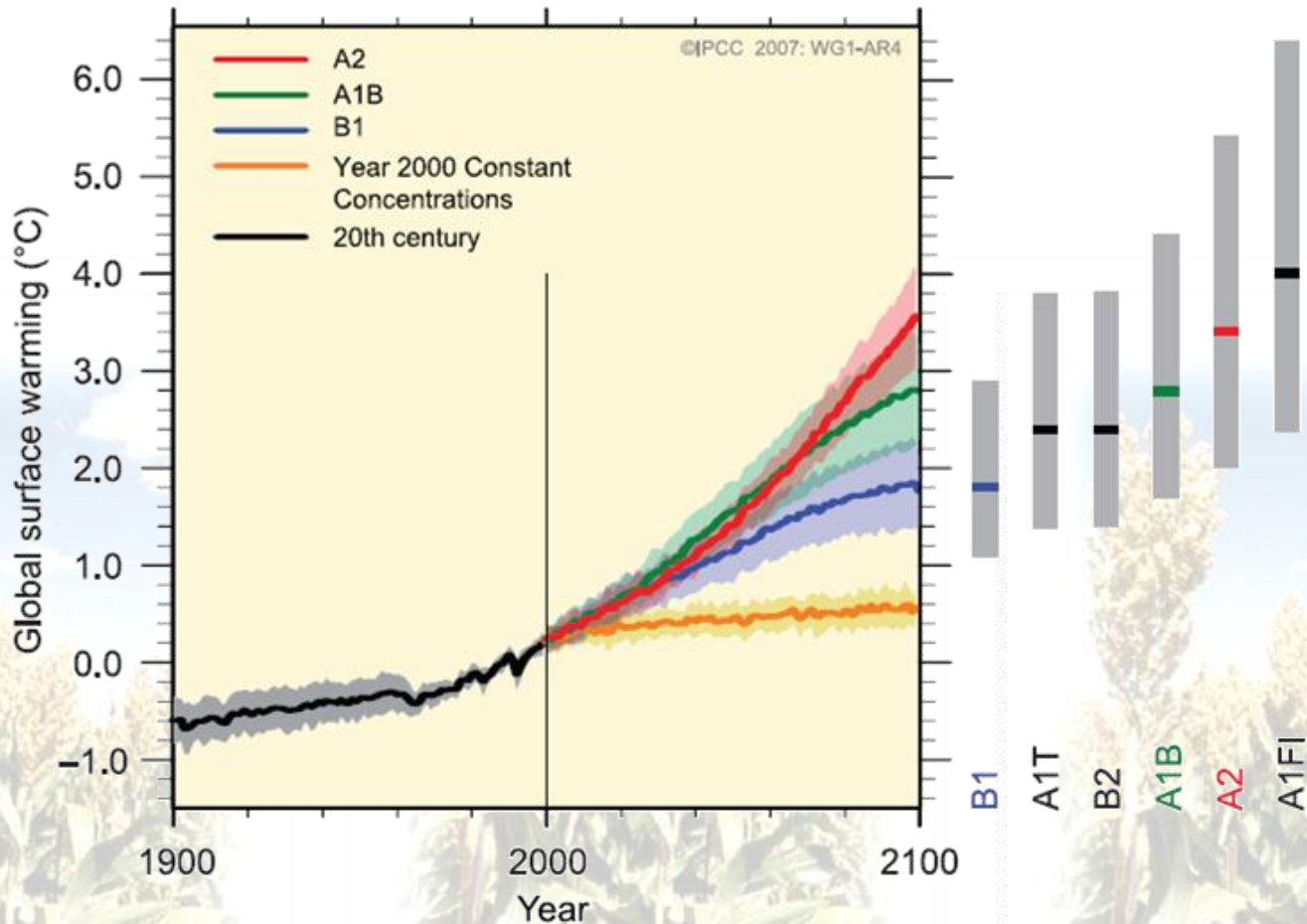


There are two General Circulation Models (3 sites) for El Salvador

# 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)

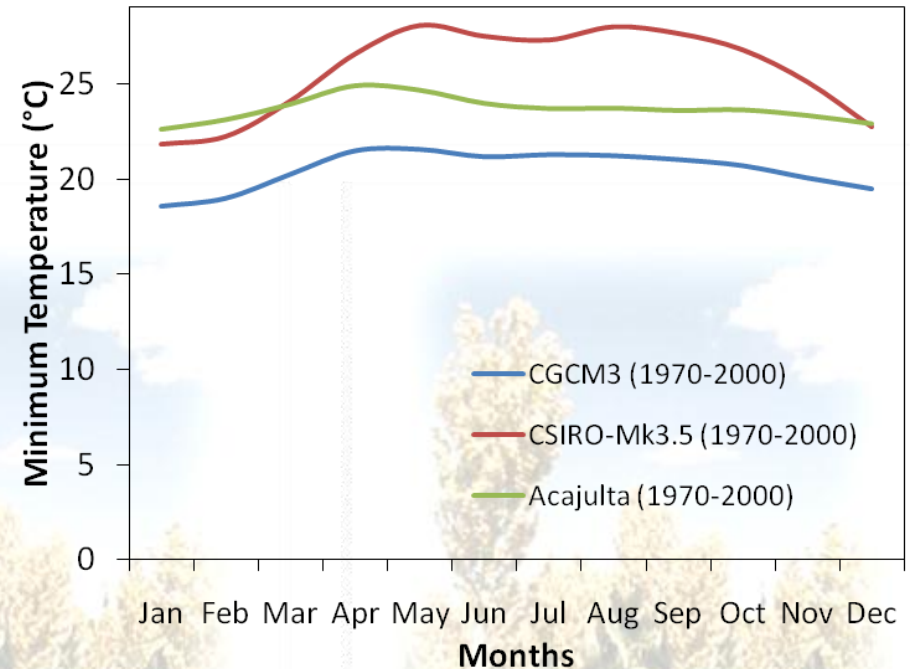
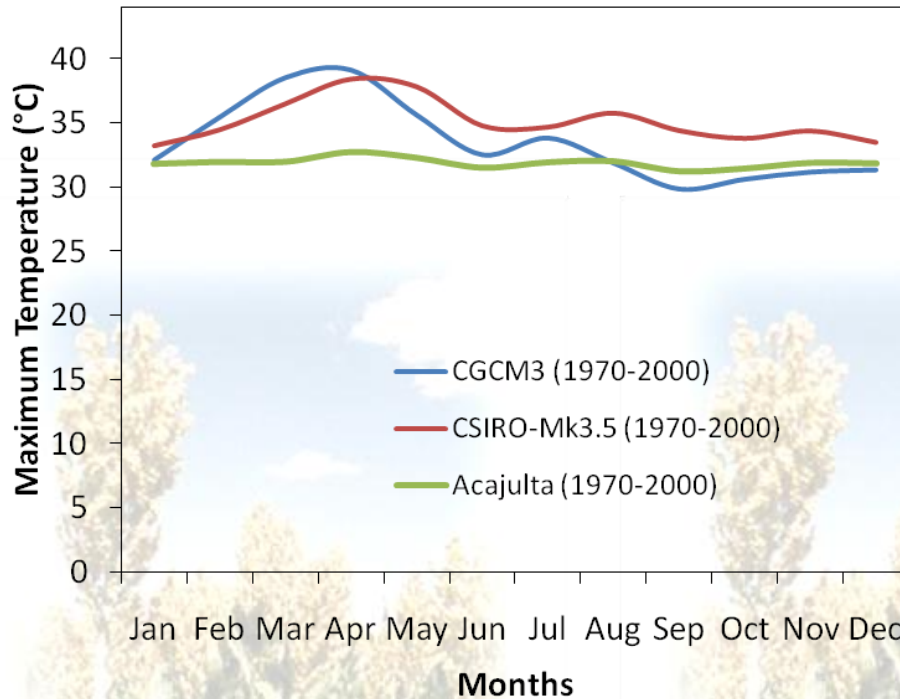
# IPCC Scenarios Used for Simulations



Three scenarios (A1B, A2 and B1) were used for simulations.

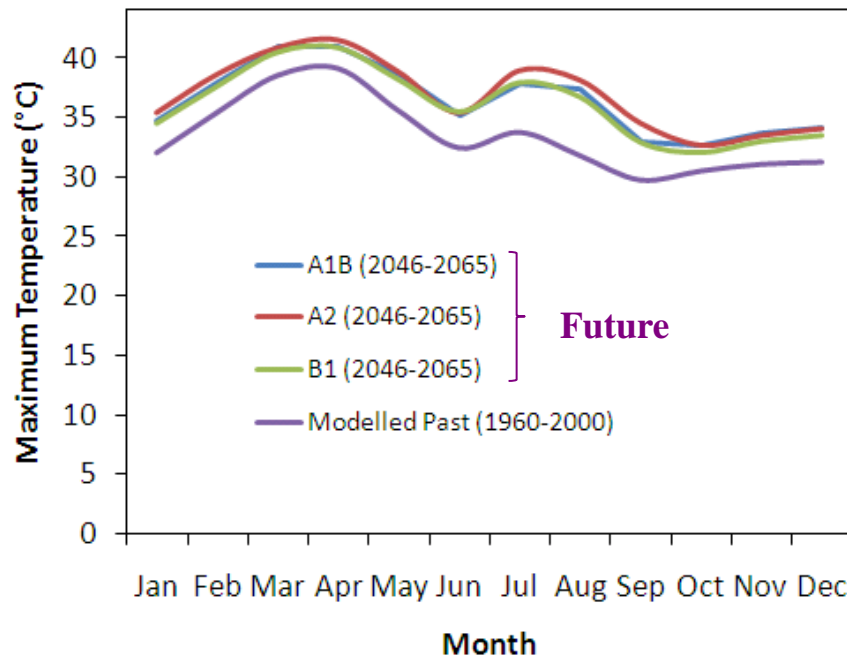


# El Salvador: Model Uncertainties: Past

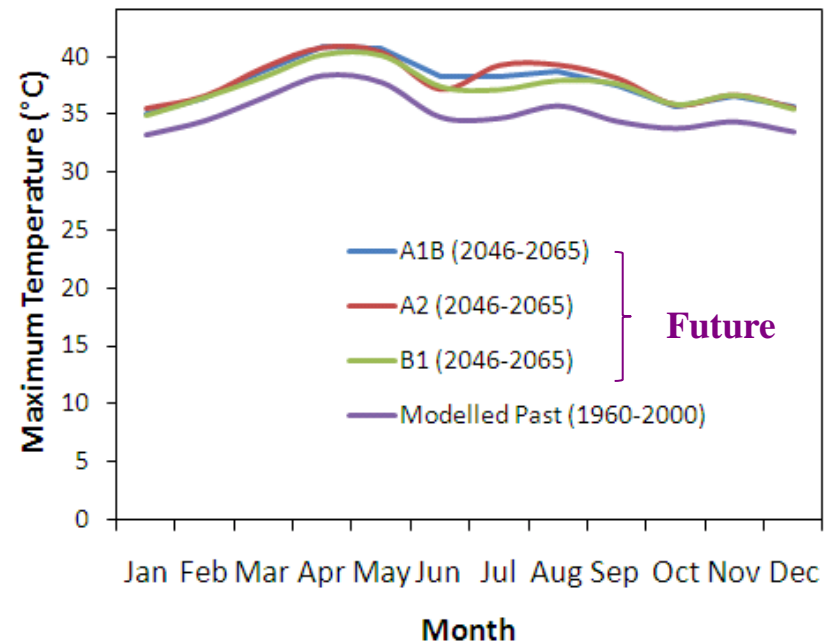


**There are uncertainties in different models of past data (1970 - 2000) from Acajulta (El Salvador)**

# El Salvador: Uncertainties in Emission Scenarios: Future: Maximum Temperature



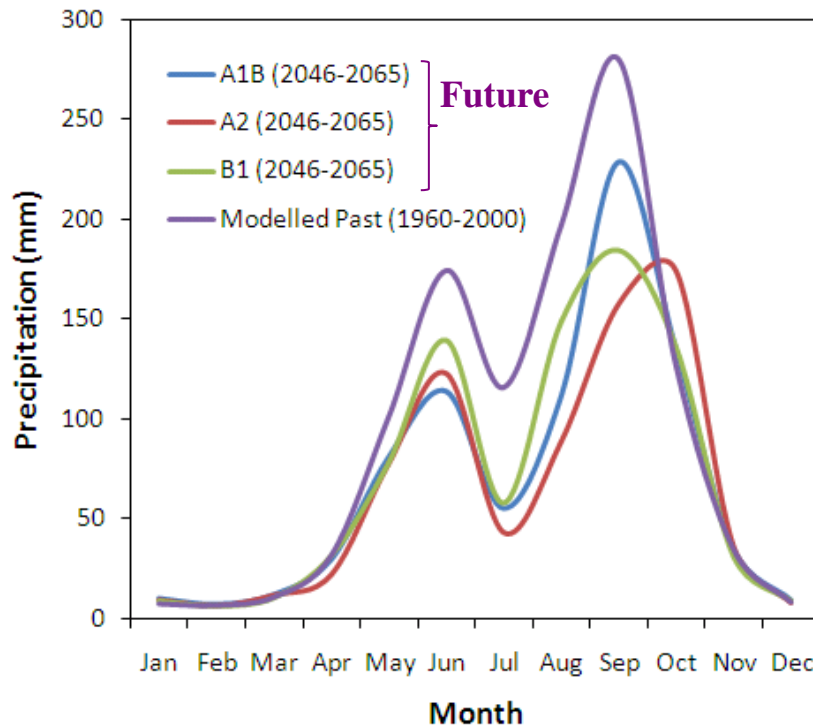
CGCM3.1 (T47)



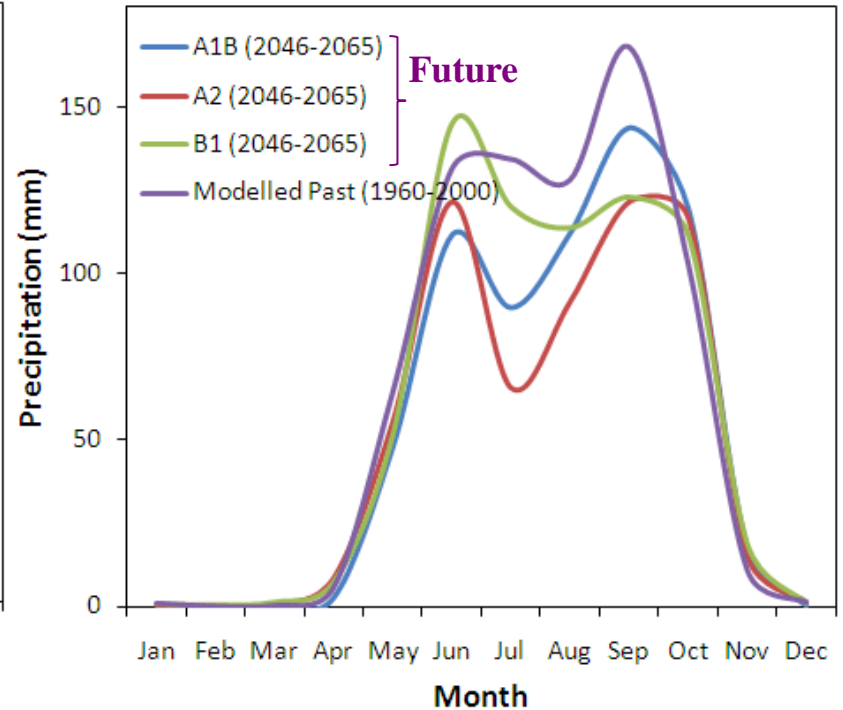
CSIRO-Mk3.5

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

# El Salvador: Uncertainties in Emission Scenarios: Future: Precipitation



CGCM3.1 (T47)



CSIRO-Mk3.5

**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

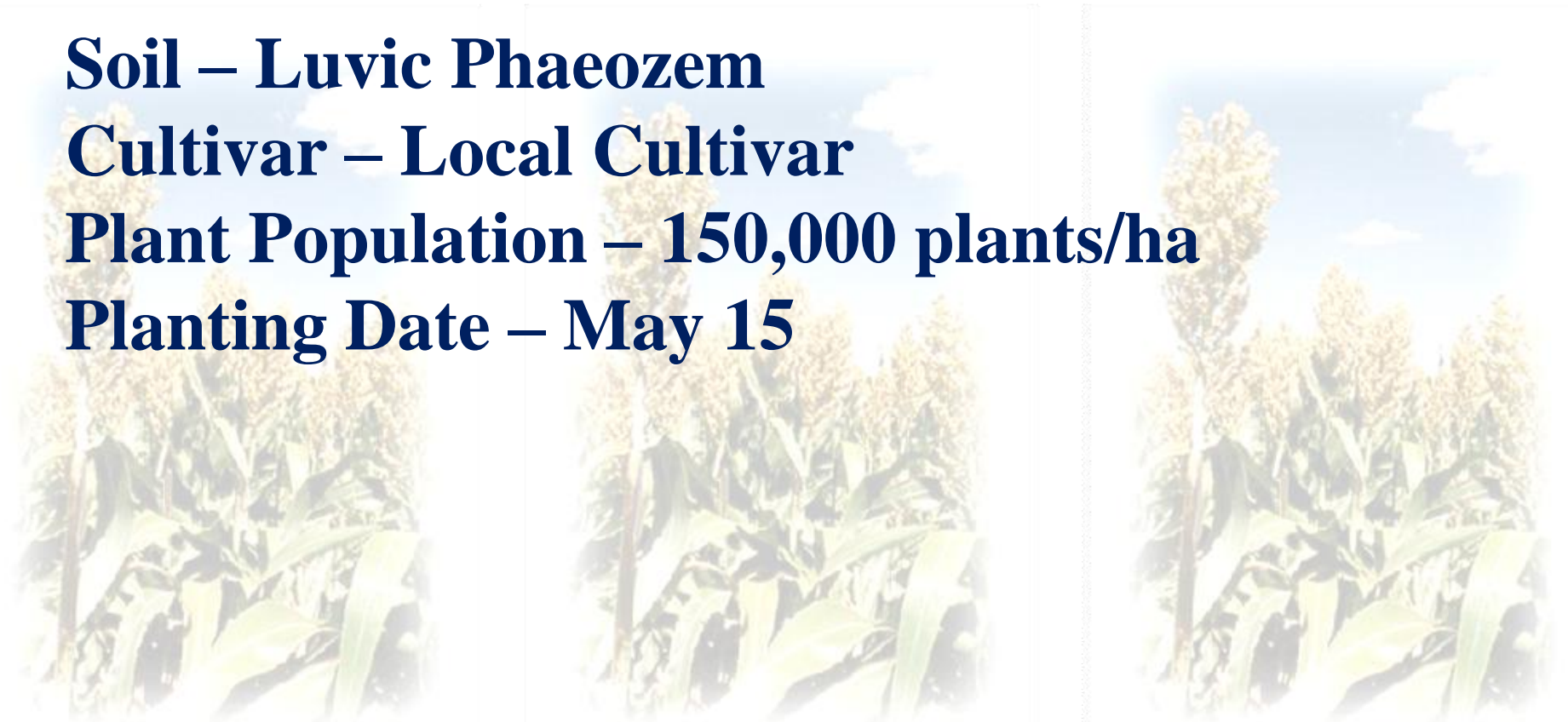
## Grain Sorghum Model (DSSAT Suite)

**Soil – Luvic Phaeozem**

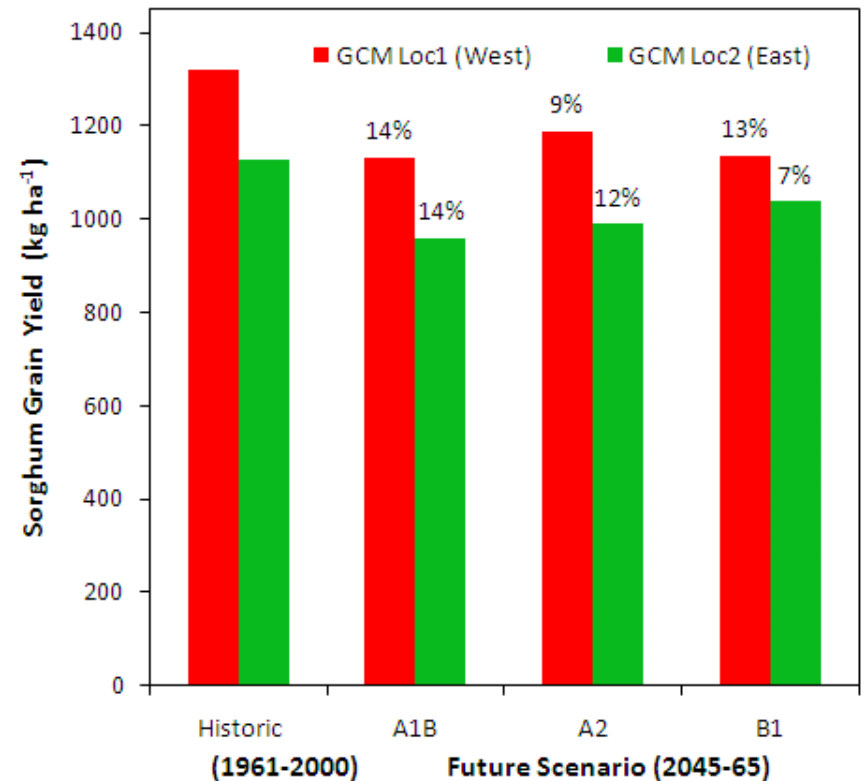
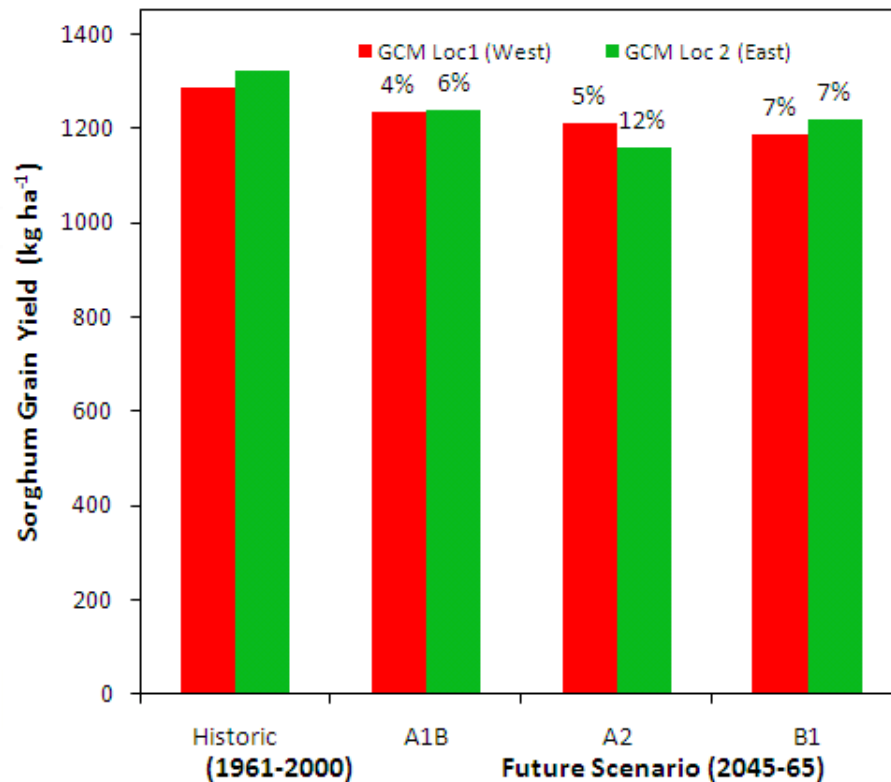
**Cultivar – Local Cultivar**

**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**

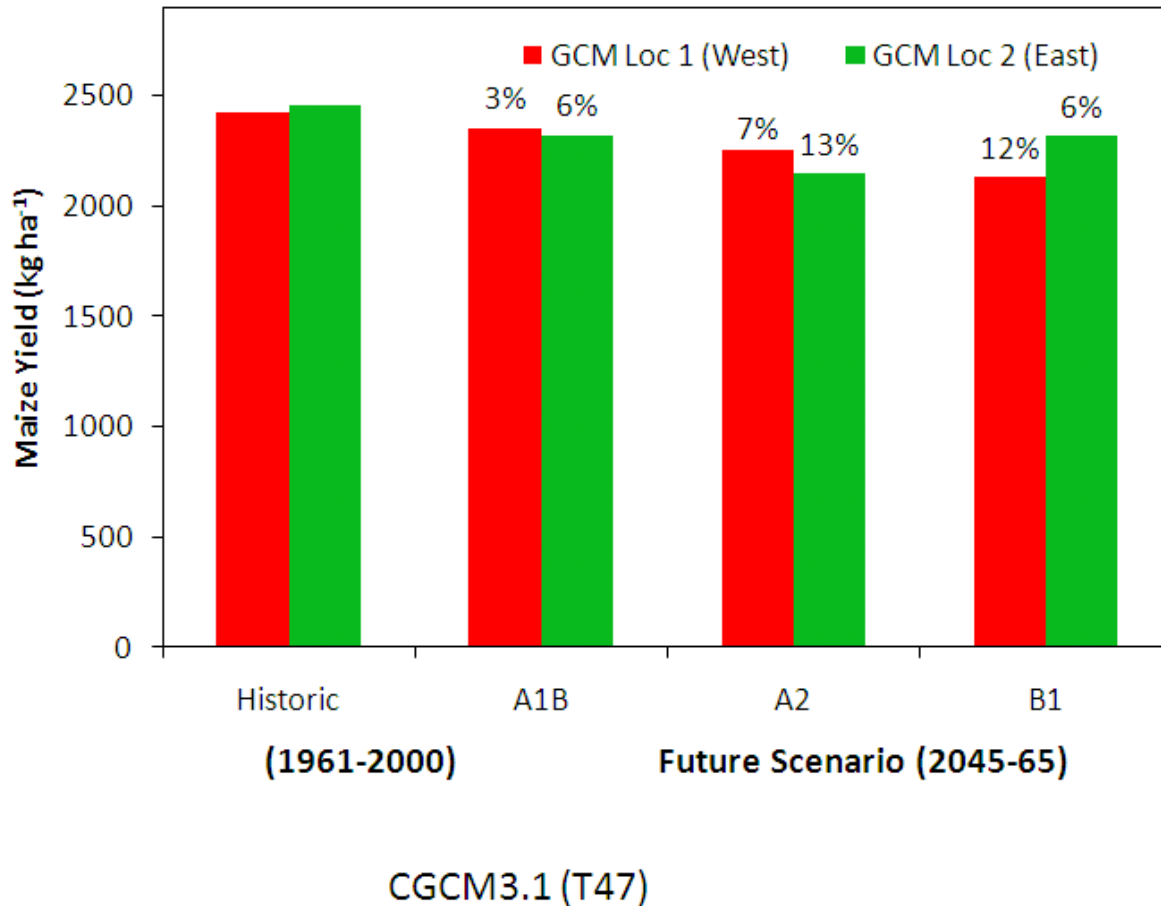
**Cultivar – Medium Season Local Cultivar**

**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**

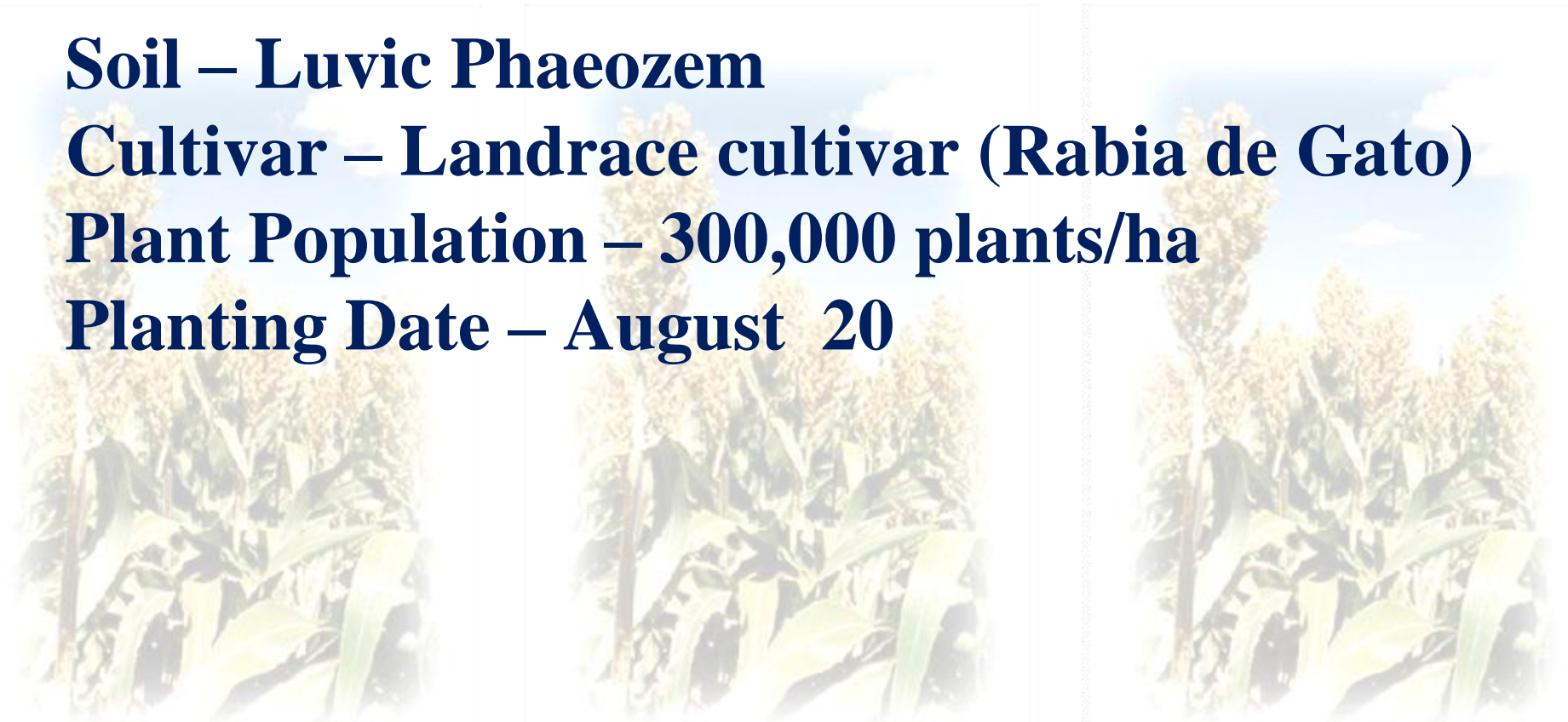
## **Dry Bean (DSSAT Suite)**

**Soil – Luvic Phaeozem**

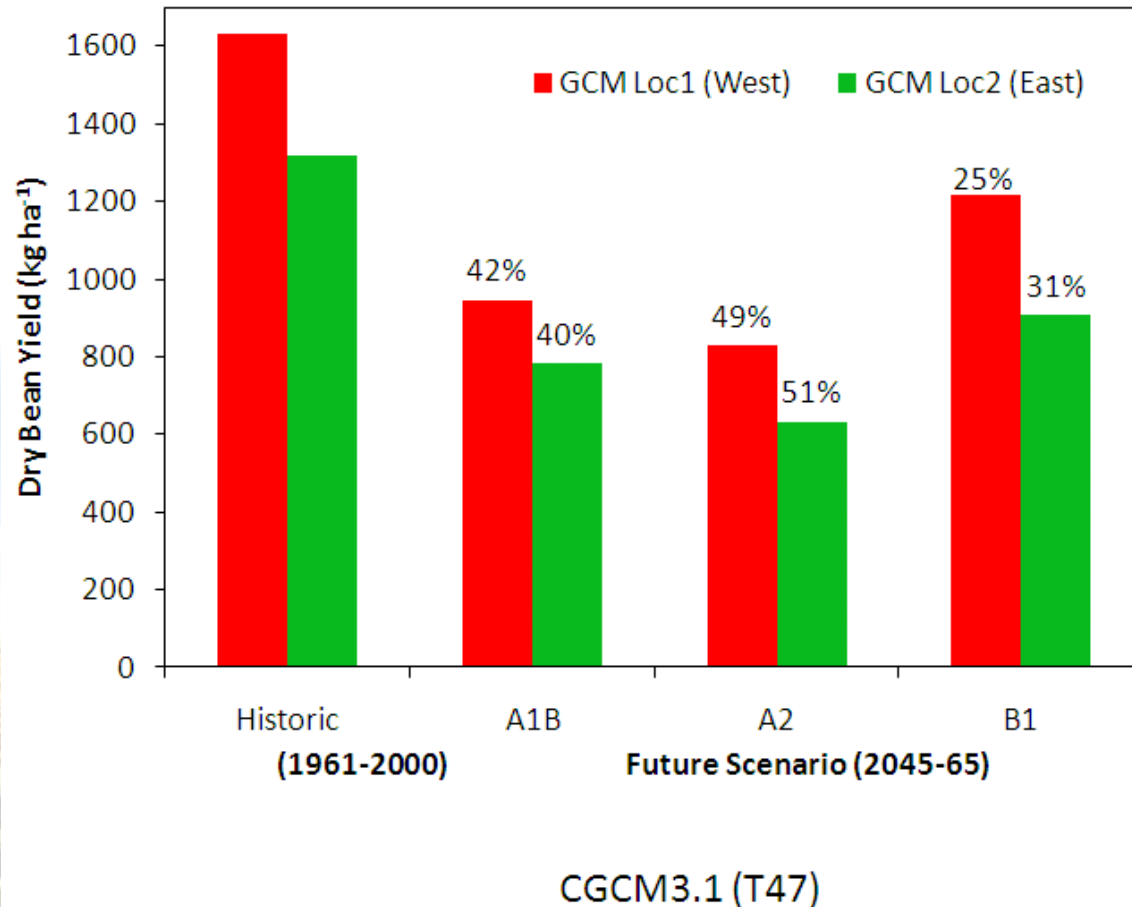
**Cultivar – Landrace cultivar (Rabia de Gato)**

**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.**



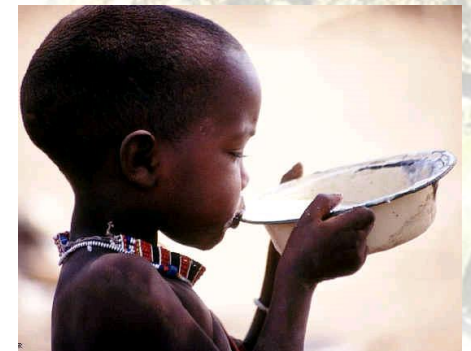
# Important Notations

**“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)



# Acknowledgements



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(KSU)



**G. Paul**  
(PhD Student KSU)



**COLLEGE OF AGRICULTURE**  
**KANSAS STATE UNIVERSITY**



**USAID**  
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**University of Florida**

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