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

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Center for SORGHUM Improvement

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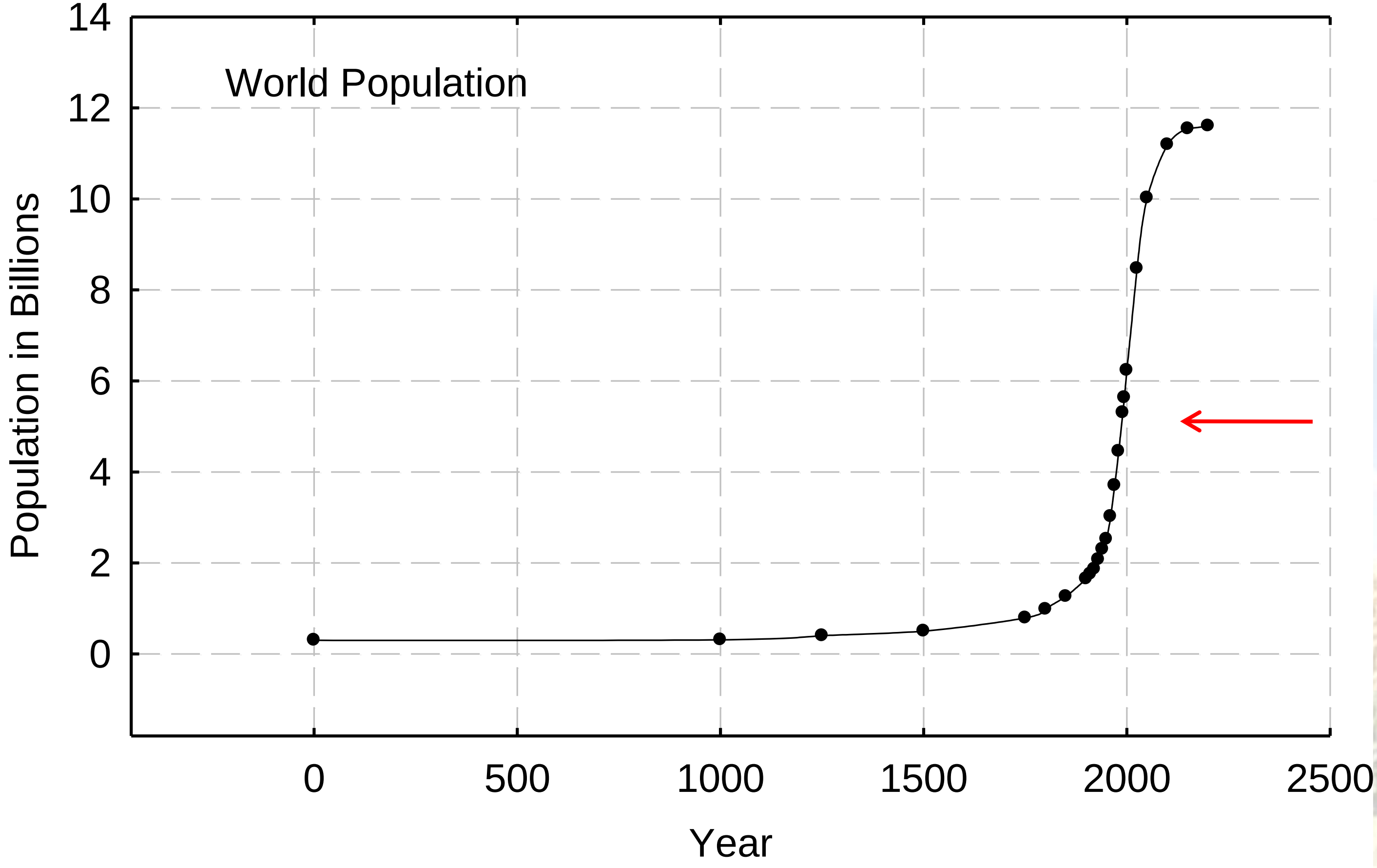
Outline

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.

Part I: Climate Change and Climate Variability

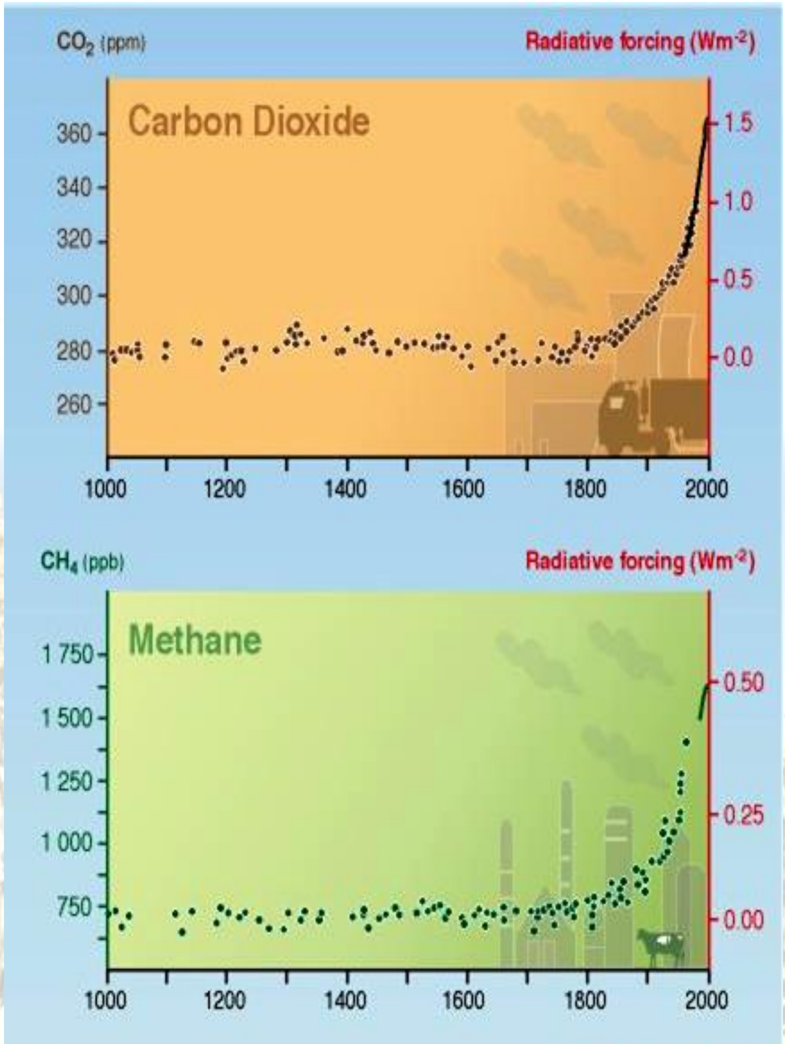
Past, Current and Future Population

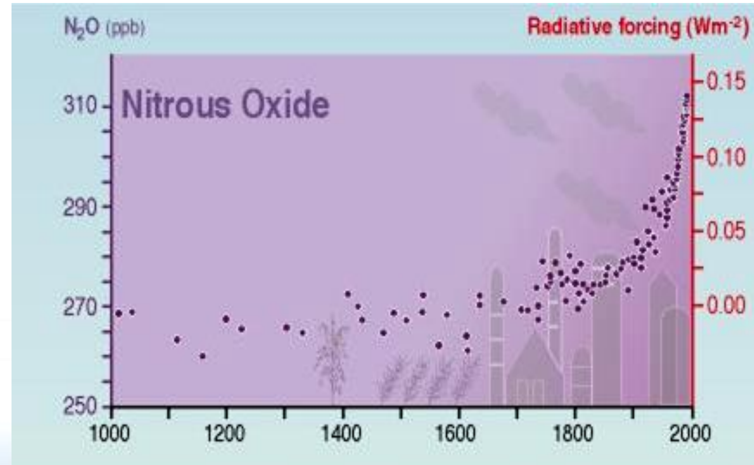
World: Current Population (20 April 2011): 6,913,282,002
El Salvador: Current Population (2010): 6,973,500

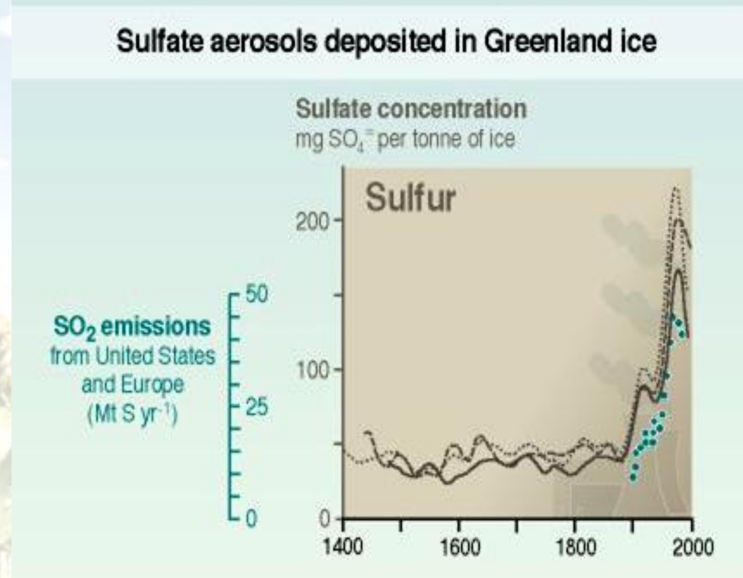


World population is continuing to increase dramatically.

Greenhouse Gases (Past Changes)

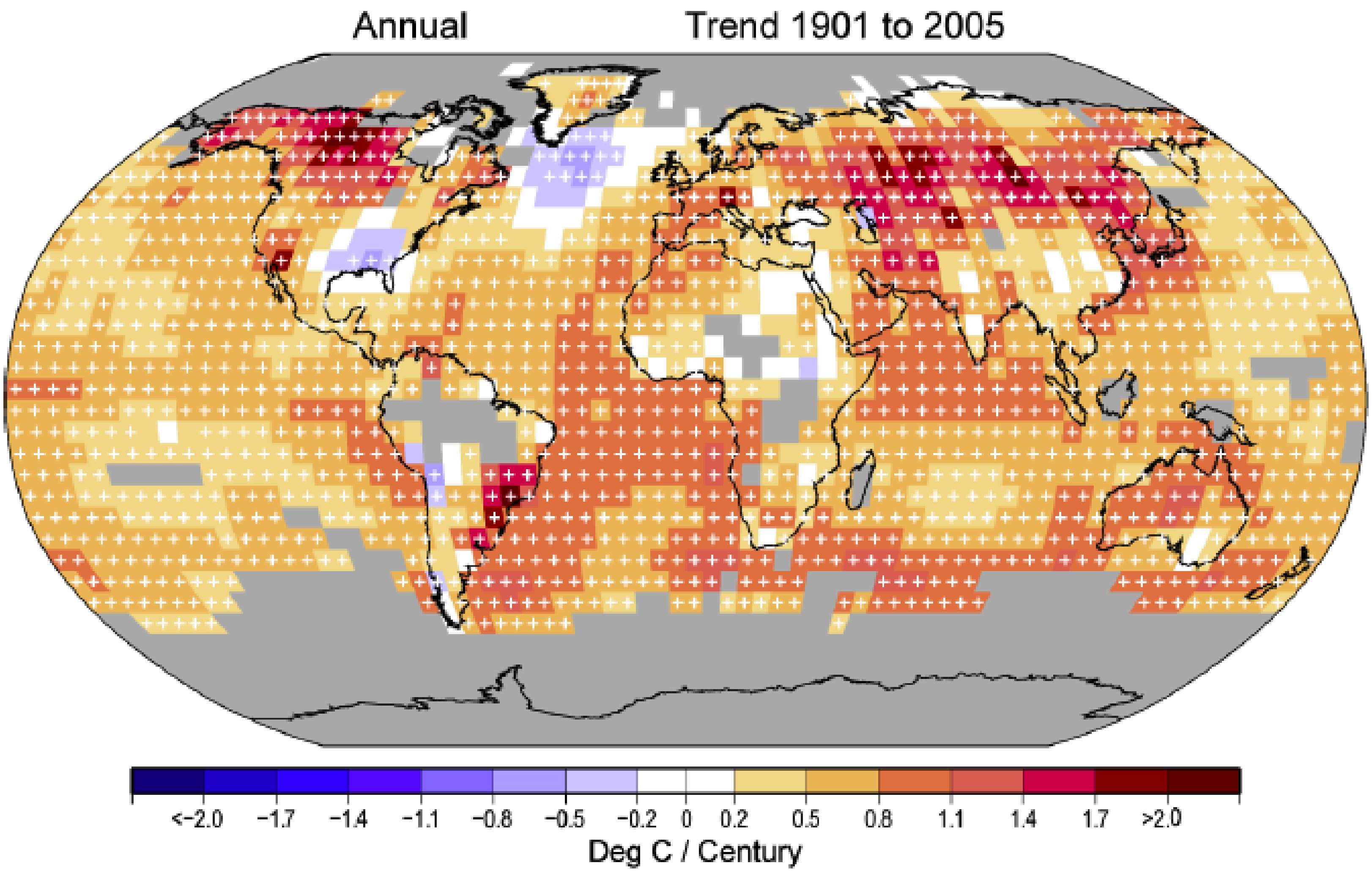






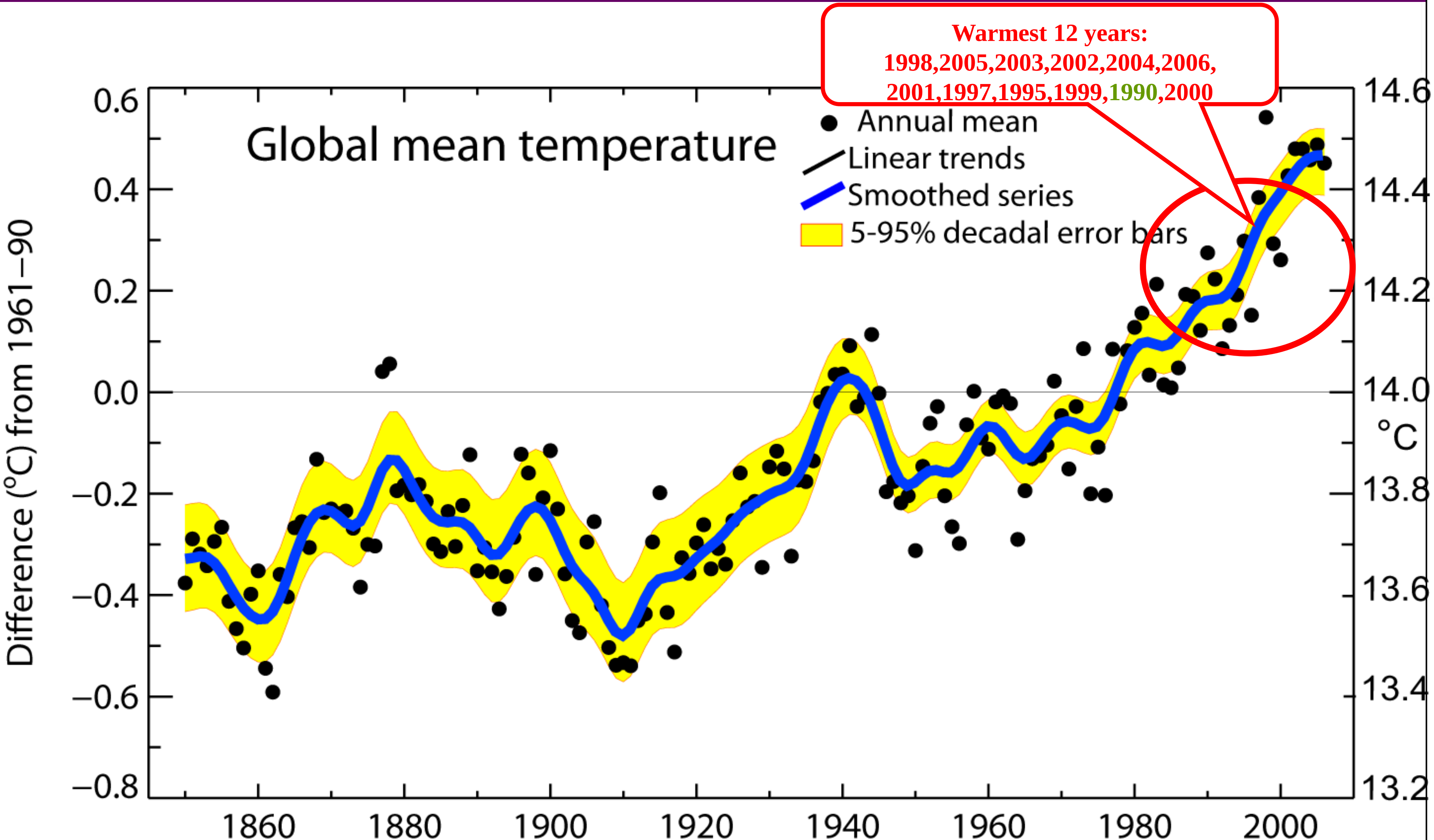
Concentrations of CO_2, CH_4, N_2O and SO_4 have dramatically increased in the recent years since 1950.

Annual Temperature Trends (1901-2005)



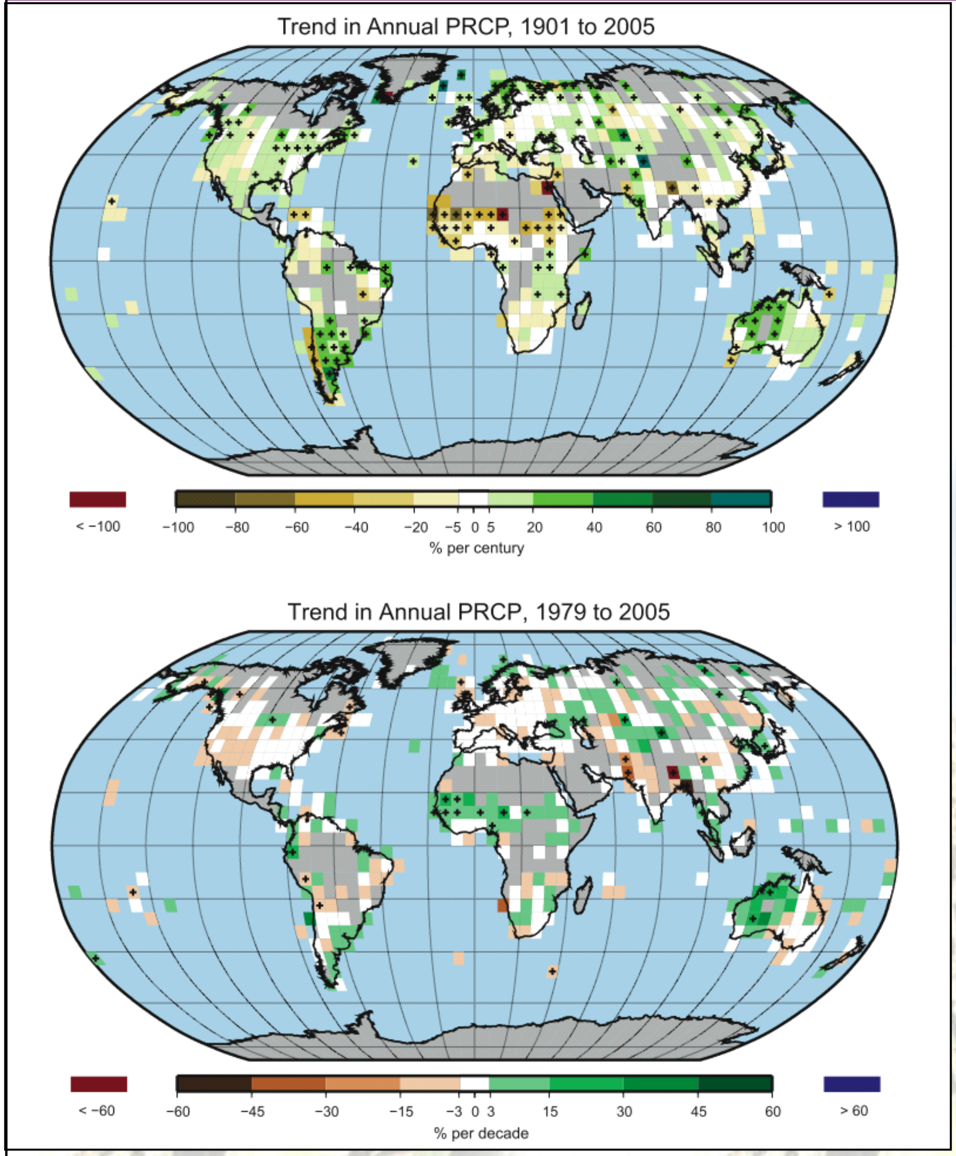
Surface air temperatures increased on average by 0.75ºC.
The world has warmed up !

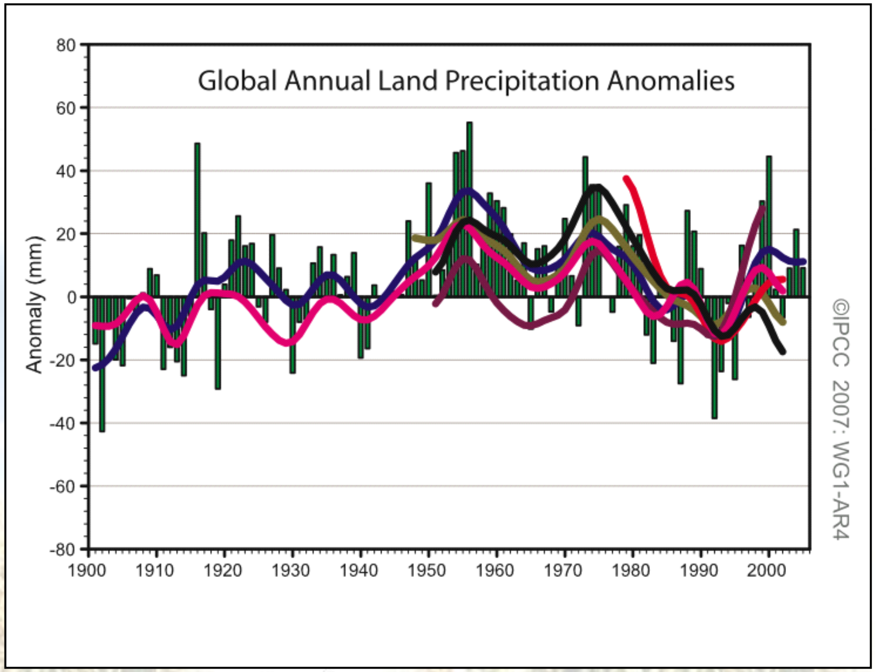
Frequency of Warm Years



Annual temperature have changed rapidly in recent years.

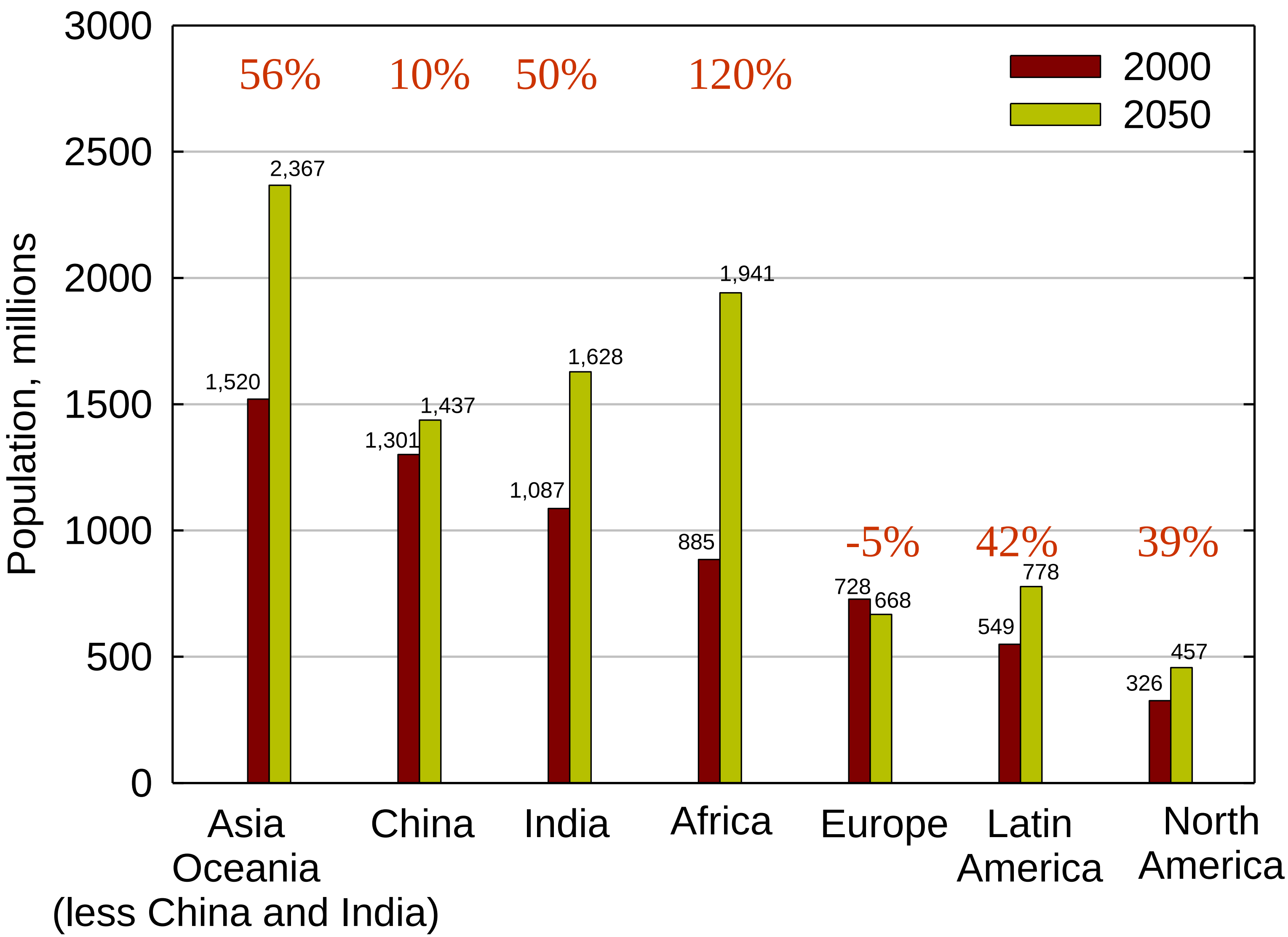
Annual Precipitation Trends (1901-2005)





Annual precipitation slightly changed and has become variable.

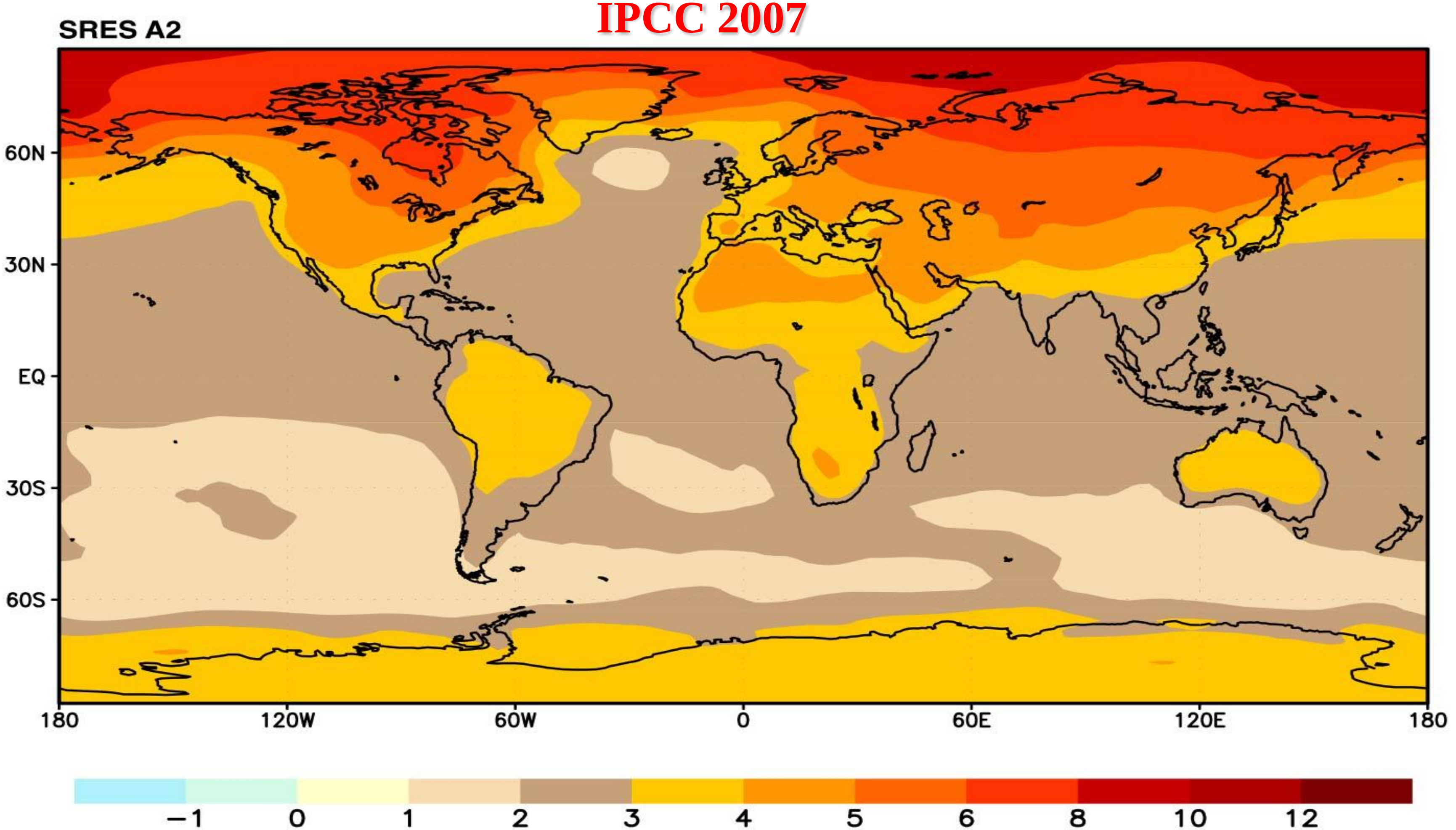
Future Population Growth: Major Countries



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

Future Changes in Mean Temperature (2100)

IPCC 2007



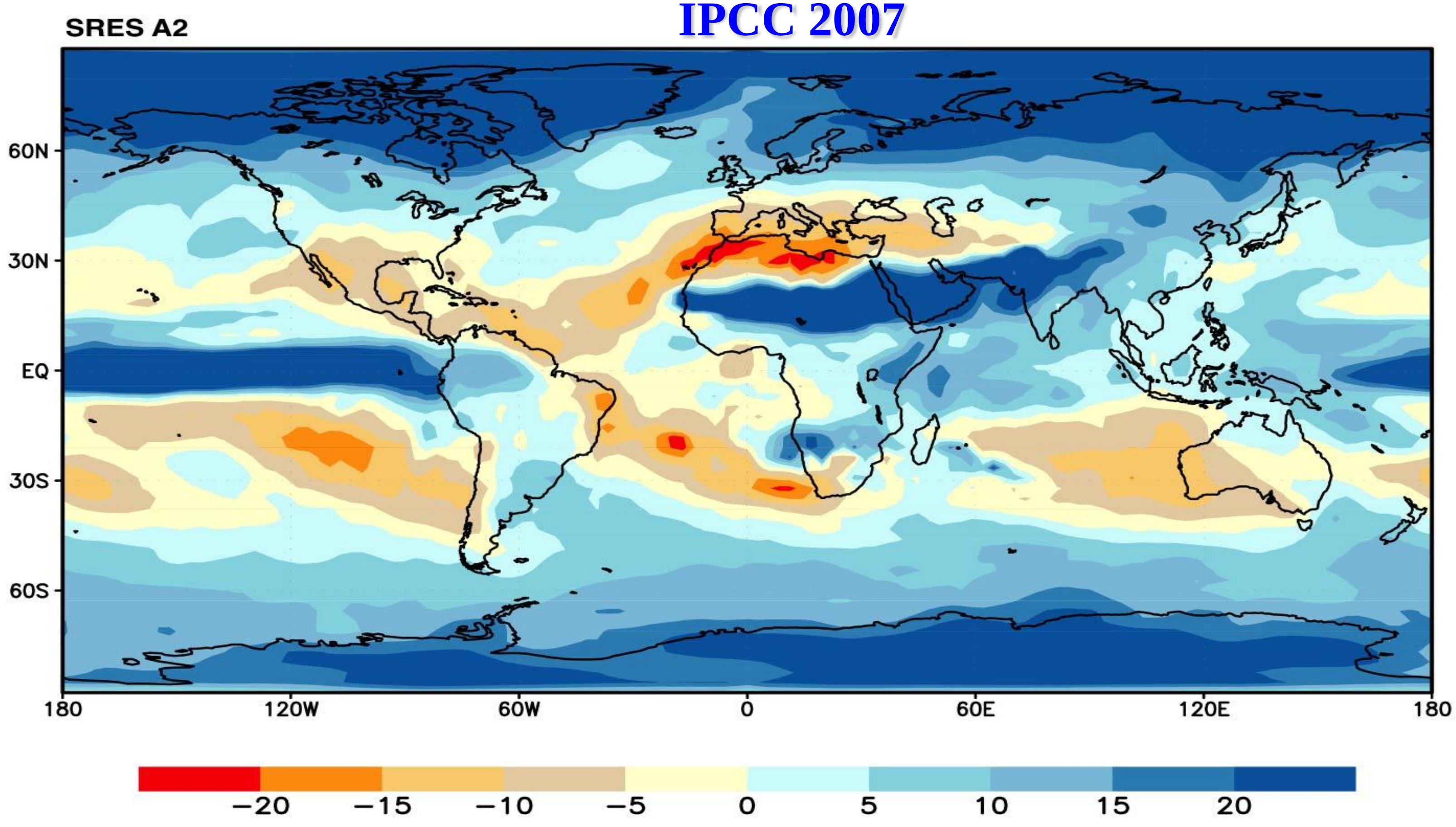
Models predict air temperatures to increase by 1.4 to 5.8°C.

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

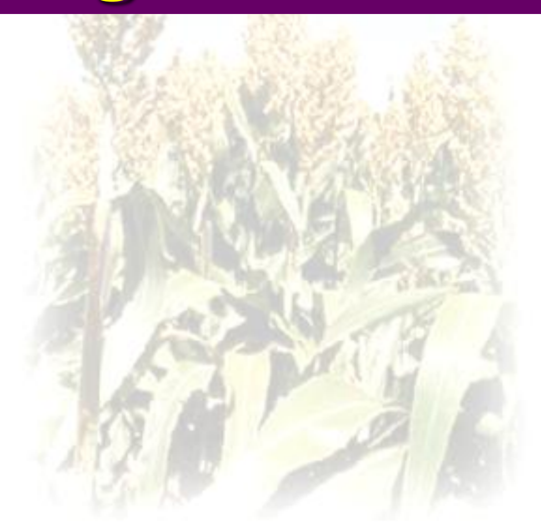


Models predict annual precipitation increase, but more dry spells.

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_2

Effects of high CO_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_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

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 µmol CO_2 mol^{-1})

Elevated (700 µmol CO_2 mol^{-1})

Cultivar / Hybrid: Dekalb 28E

Population: 20 plants m^{-2}

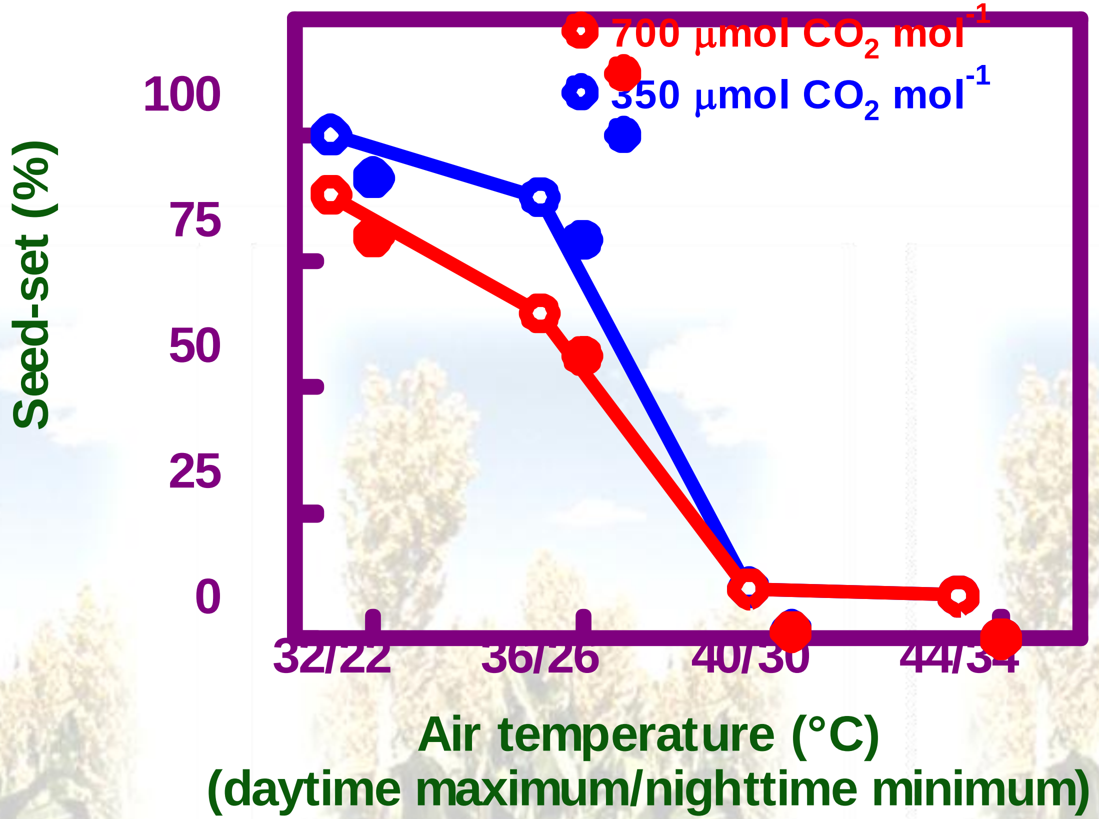
Grain Sorghum: Panicle Emergence

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

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

High temperature stress inhibited panicle emergence.

Grain Sorghum: Seed-Set

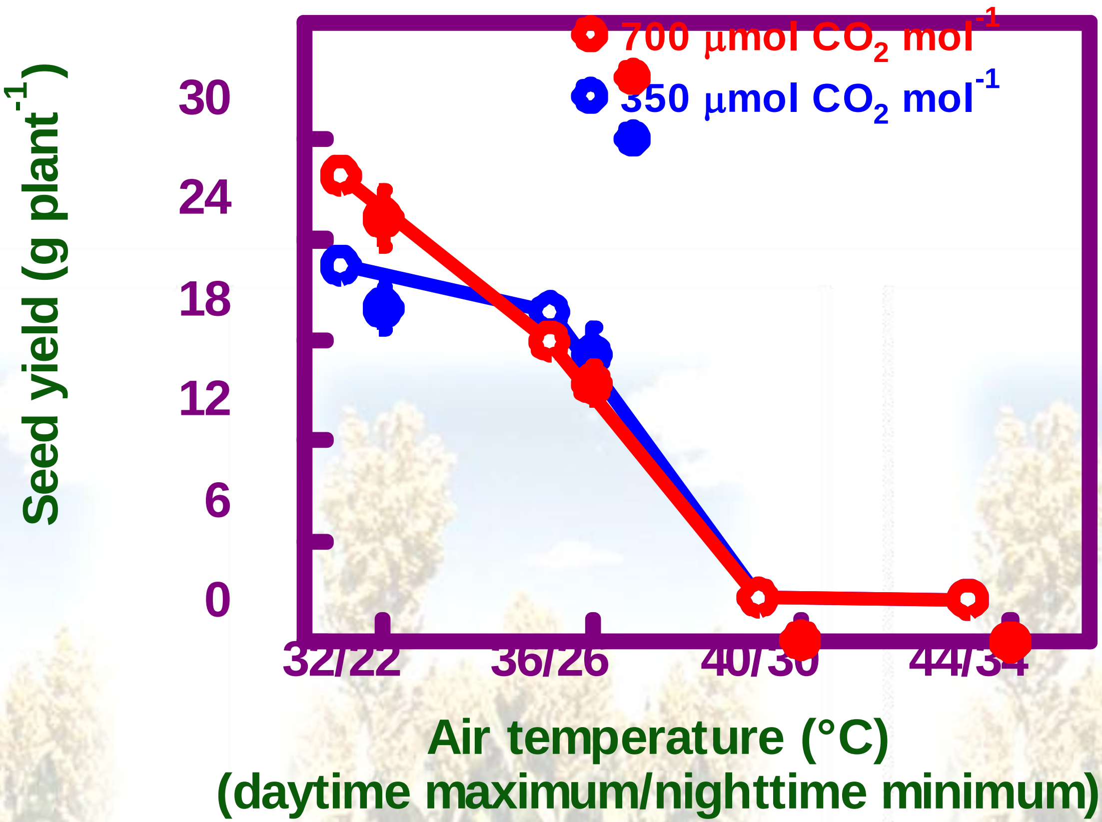


Prasad et al., 2006. Agric. For. Meterol. 139: 237-251.

Elevated temperatures decreased % seed-set.

Elevated CO_2 decreased seed-set.

Grain Sorghum: Seed Yield

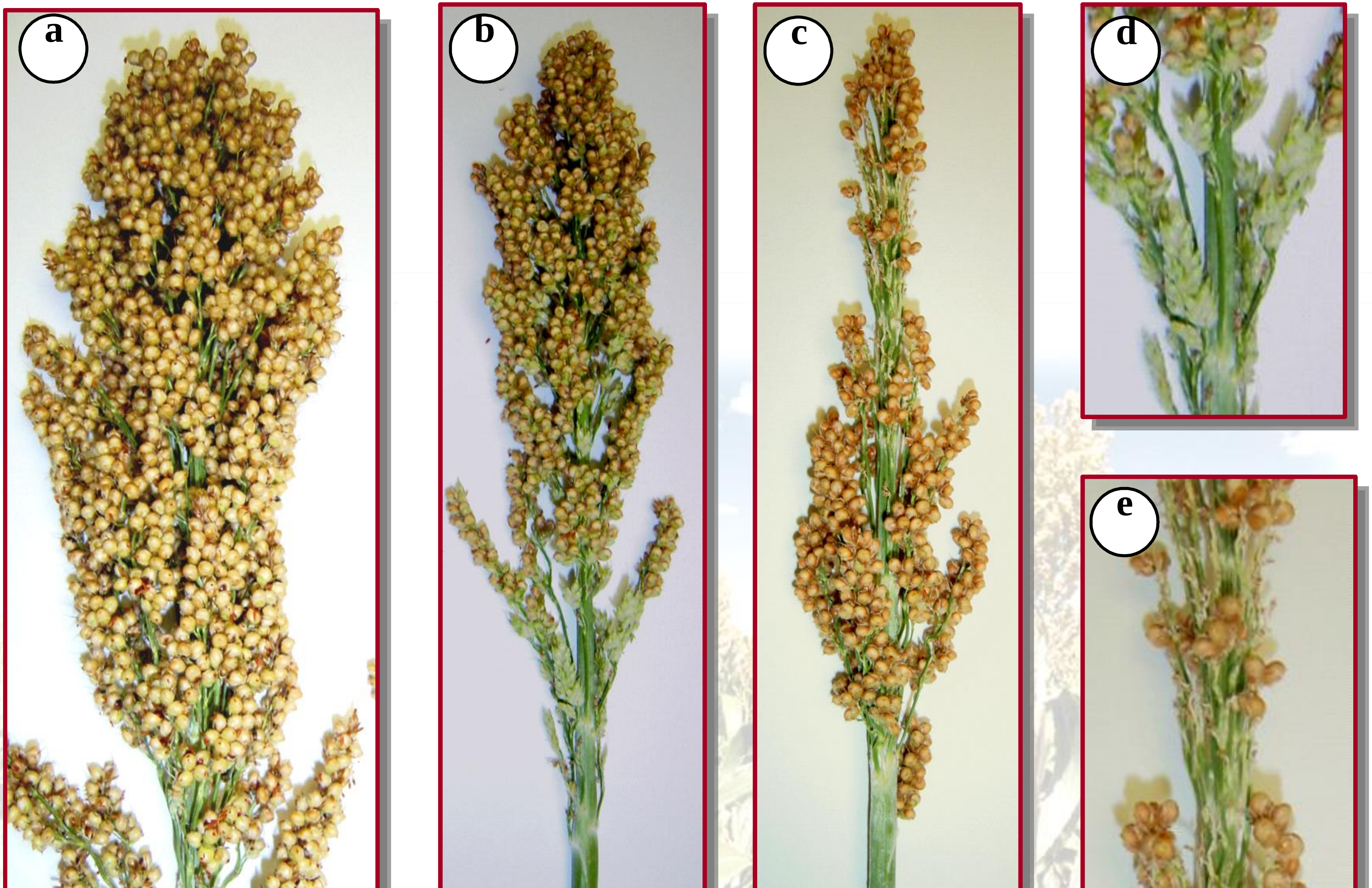


Prasad et al., 2006. Agric. For. Meterol. 139: 237-251.

Elevated temperatures decreased seed yield.
Elevated CO_2 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

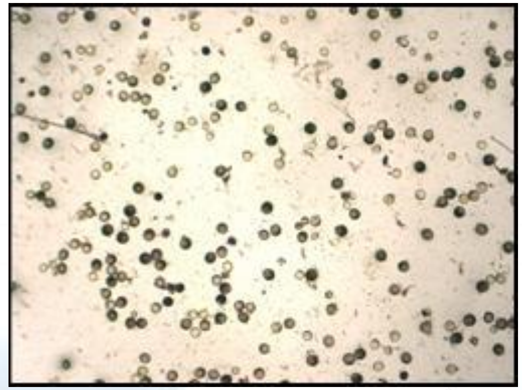


High temperature stress (10 days) decreased seed-set and seed yield.

Short Periods of High Temperature Stress – Sorghum – Pollen

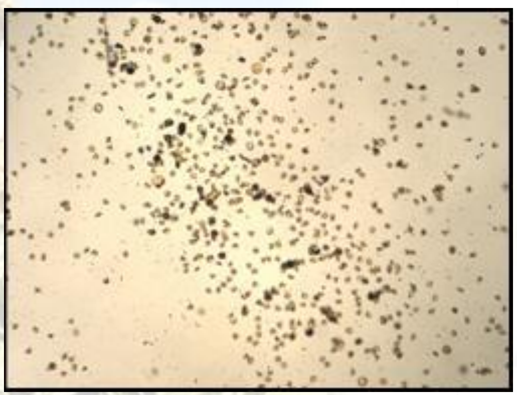
Control = 32/22 C

36/26 C

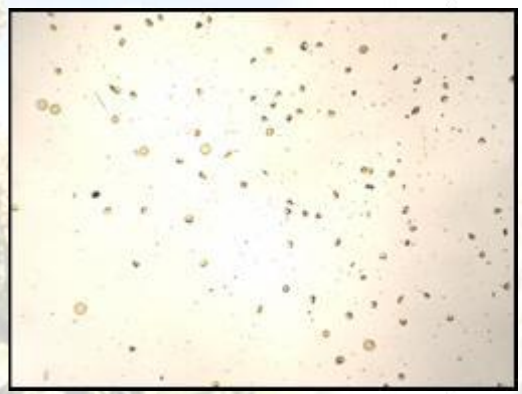


Duration = 10 days
Stage = 10 d before panicle emergence

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 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

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

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[A]
DKS-29-28	82	34	55[B]
DK-54-00	52	53	42[C]
Pioneer 84G62	55	55	40[C]

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_2

28/18, 31/21, 34/24, 37/27 and 40/30 C at Elevated CO_2

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

Carbon dioxide (2):

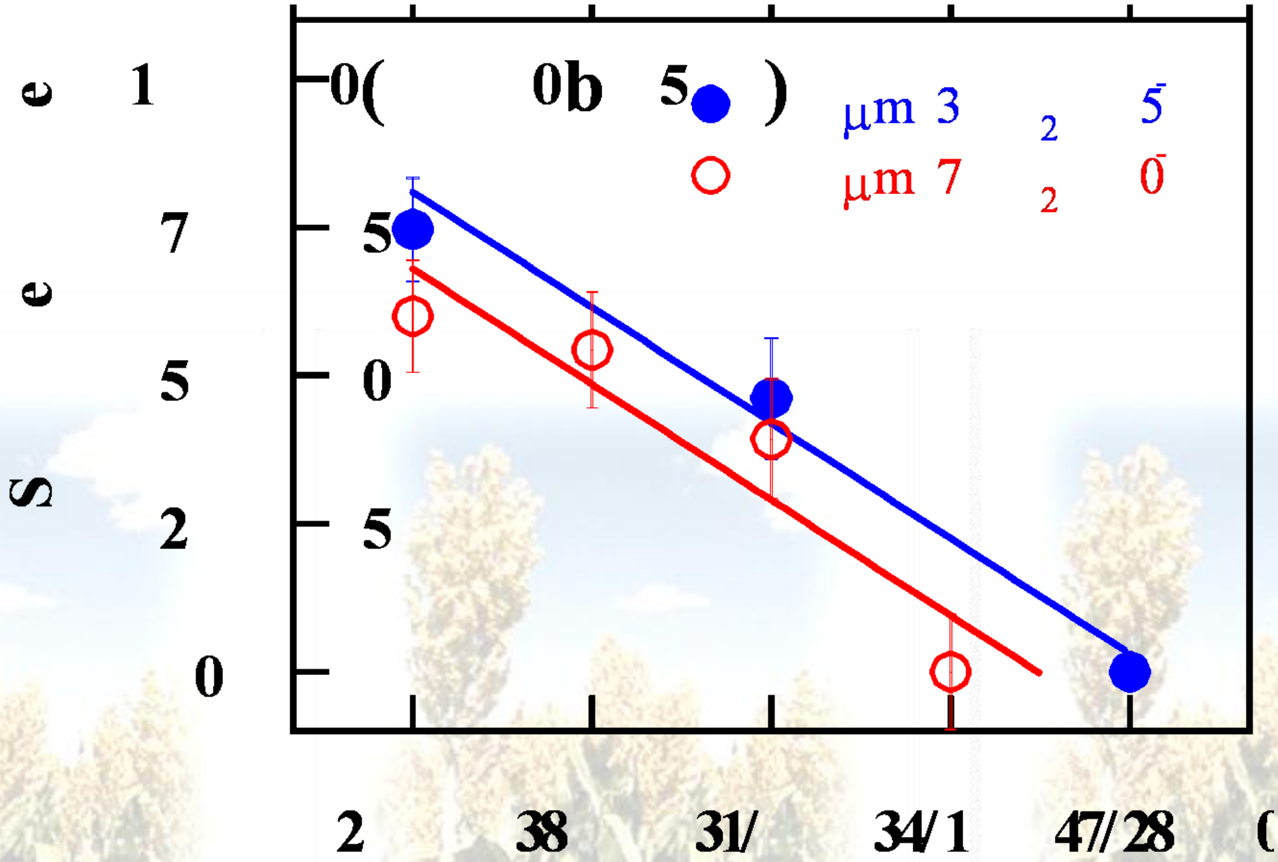
Ambient (350 µmol CO_2 mol^{-1})

Elevated (700 µmol CO_2 mol^{-1})

Cultivar: Montcalm

Population: 24 plants m^{-2}

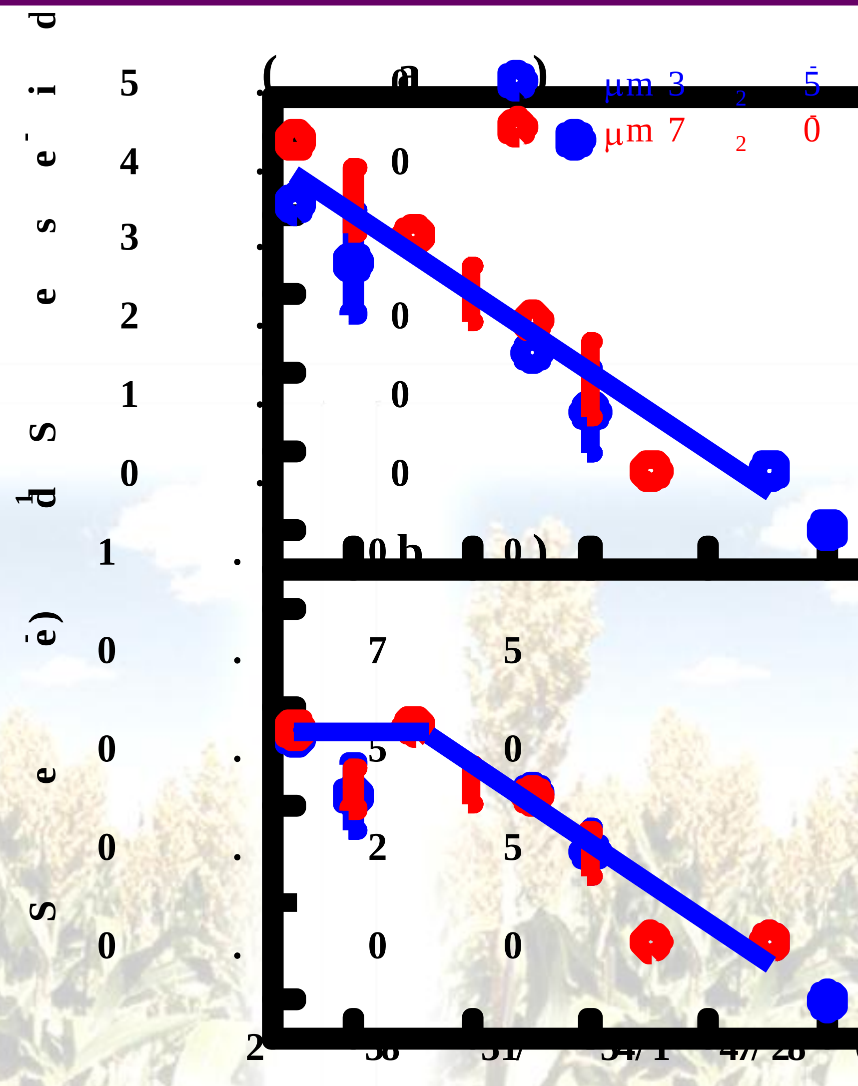
Dry Bean: Seed - set



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

Temperatures > 28/18°C decreased seed-set.
Elevated CO_2 also decreased seed-set.

Dry Bean: Seed Number and Seed Size

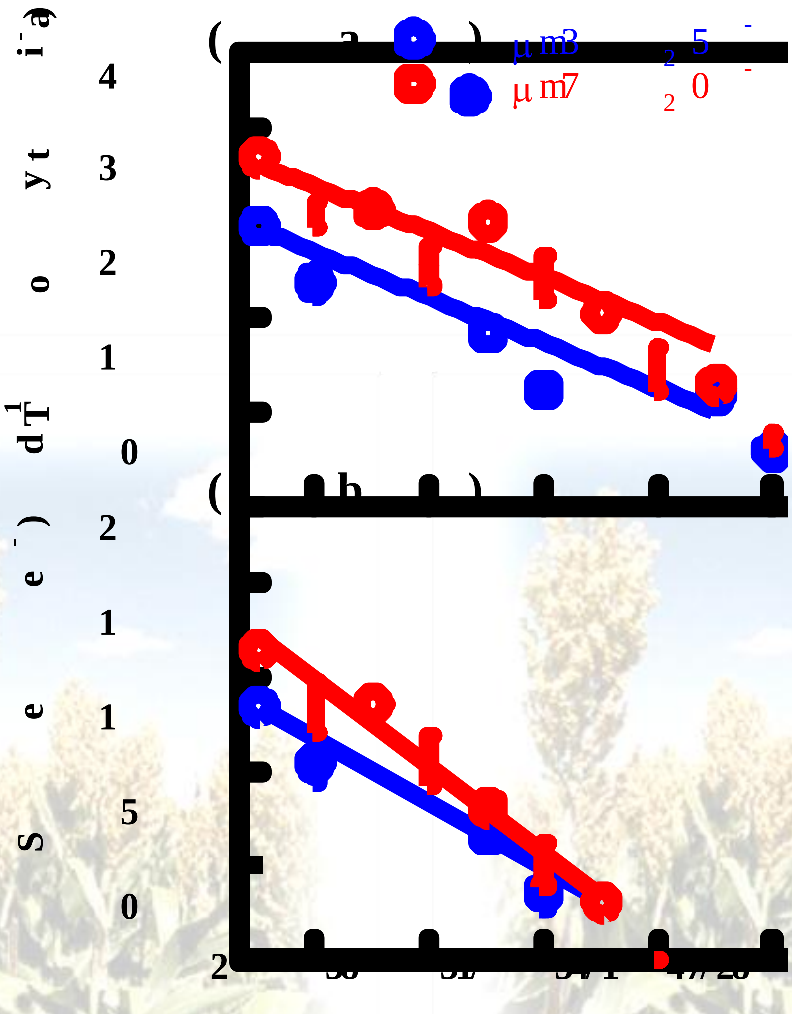


Prasad et al. (2002). Global Change Biol. 8: 710-721.

Temperatures > 28/18°C decreased seed number and seed size.

Elevated CO_2 did not influence seed number or seed size.

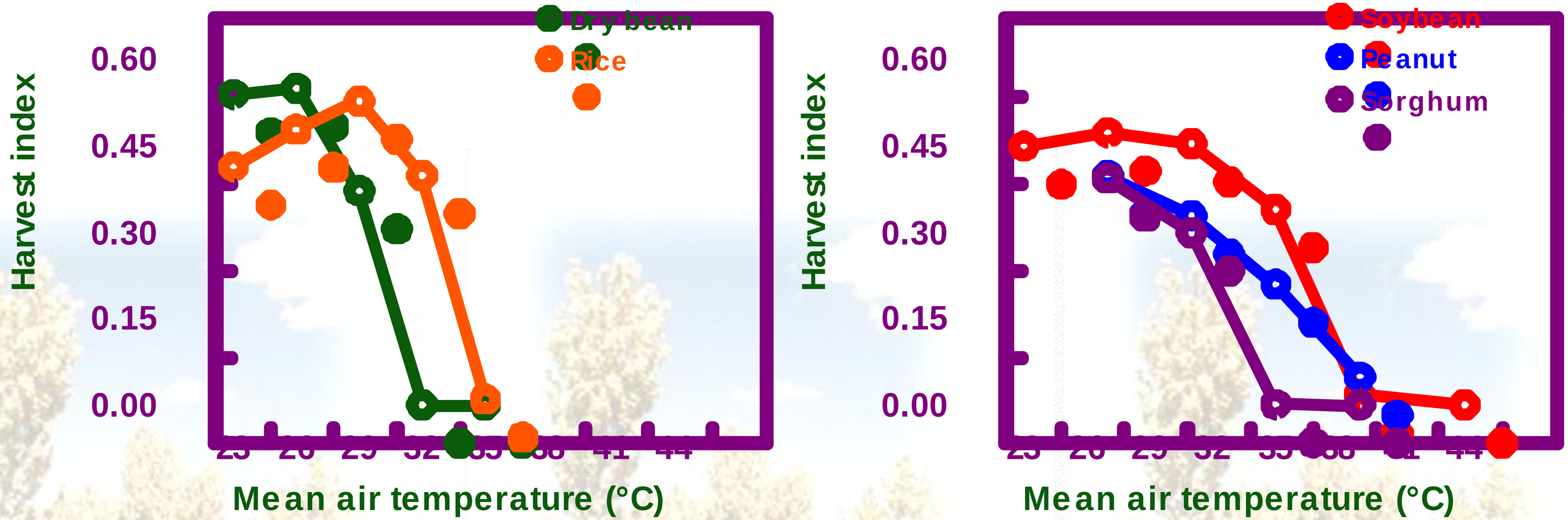
Dry Bean: Biomass and Seed Yield



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

Temperatures > 28/18°C decreased biomass.
Elevated CO_2 increased biomass.
Benefits of elevated CO_2 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. Meterol. 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

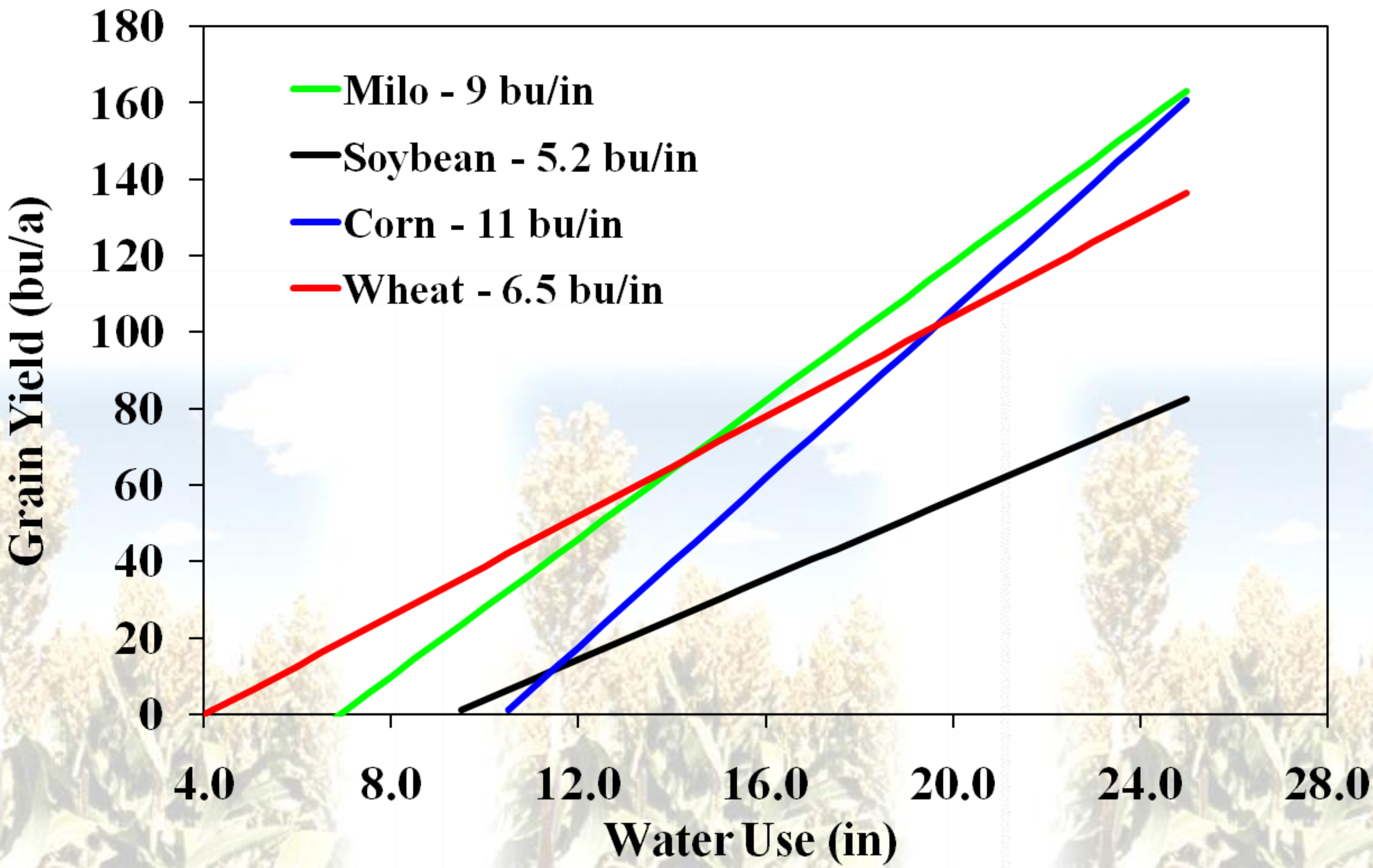
A general rule of thumb is that there will be a 10% decrease in yield for every 1 degree centigrade rise in temperature above optimum temperature for reproductive growth for that crop.

Conclusions

- **High temperature stress decreased grain yield.**
- **There were no beneficial effects of elevated CO_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

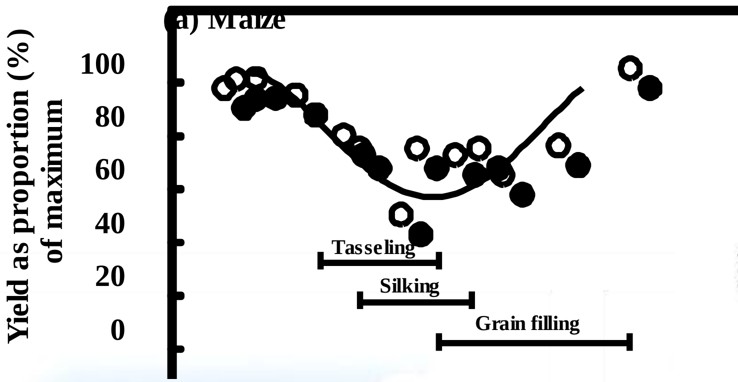
Crop Responses to Water Use



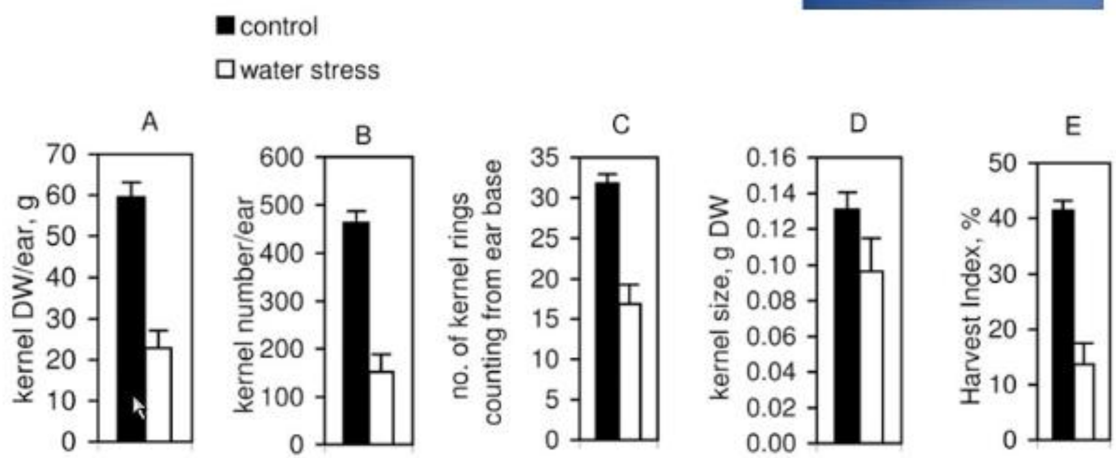
Source: Dr. L.R. Stone
Kansas State University

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

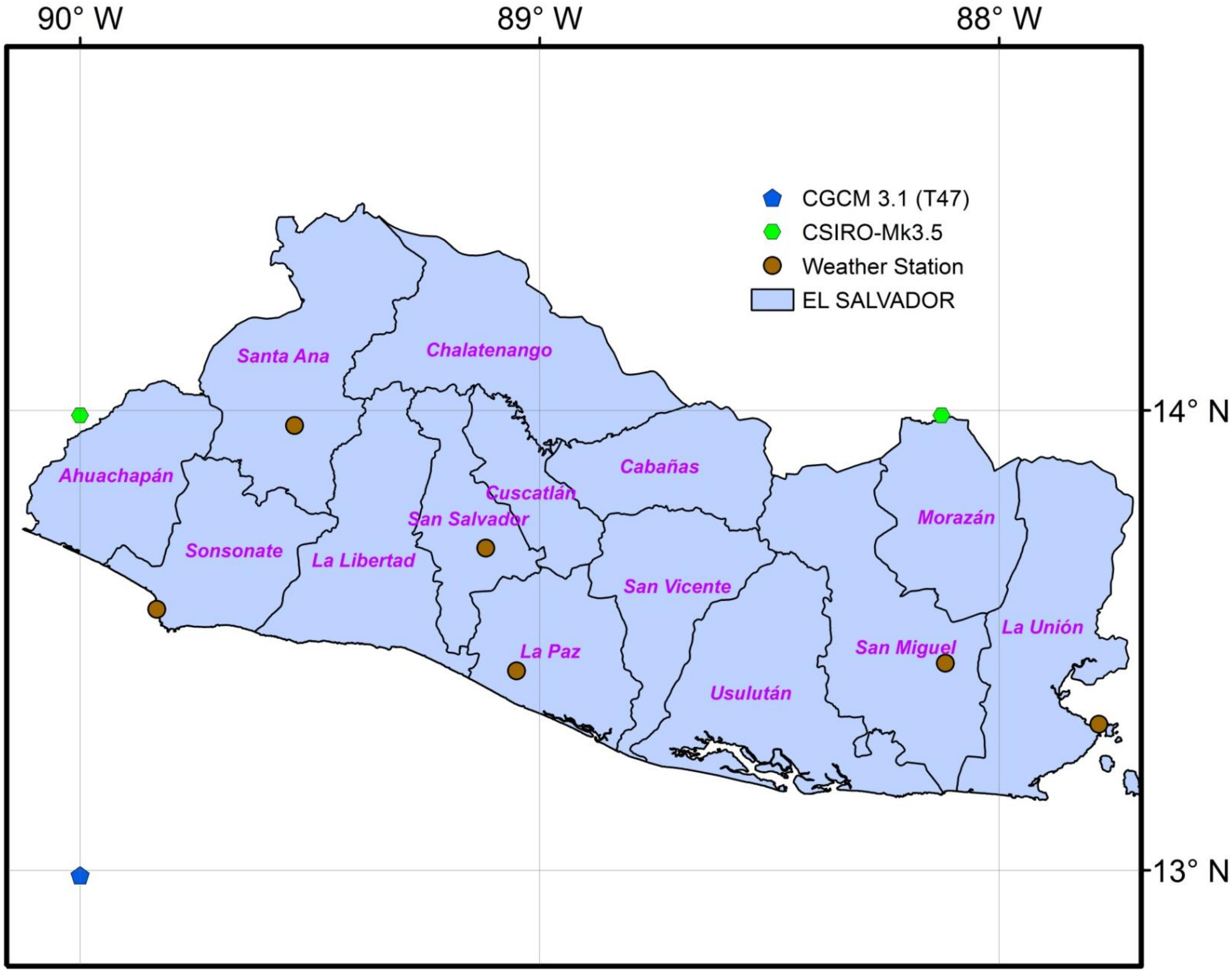


Setter TL, Parra R (2010) Crop Science **50:** 980-988

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

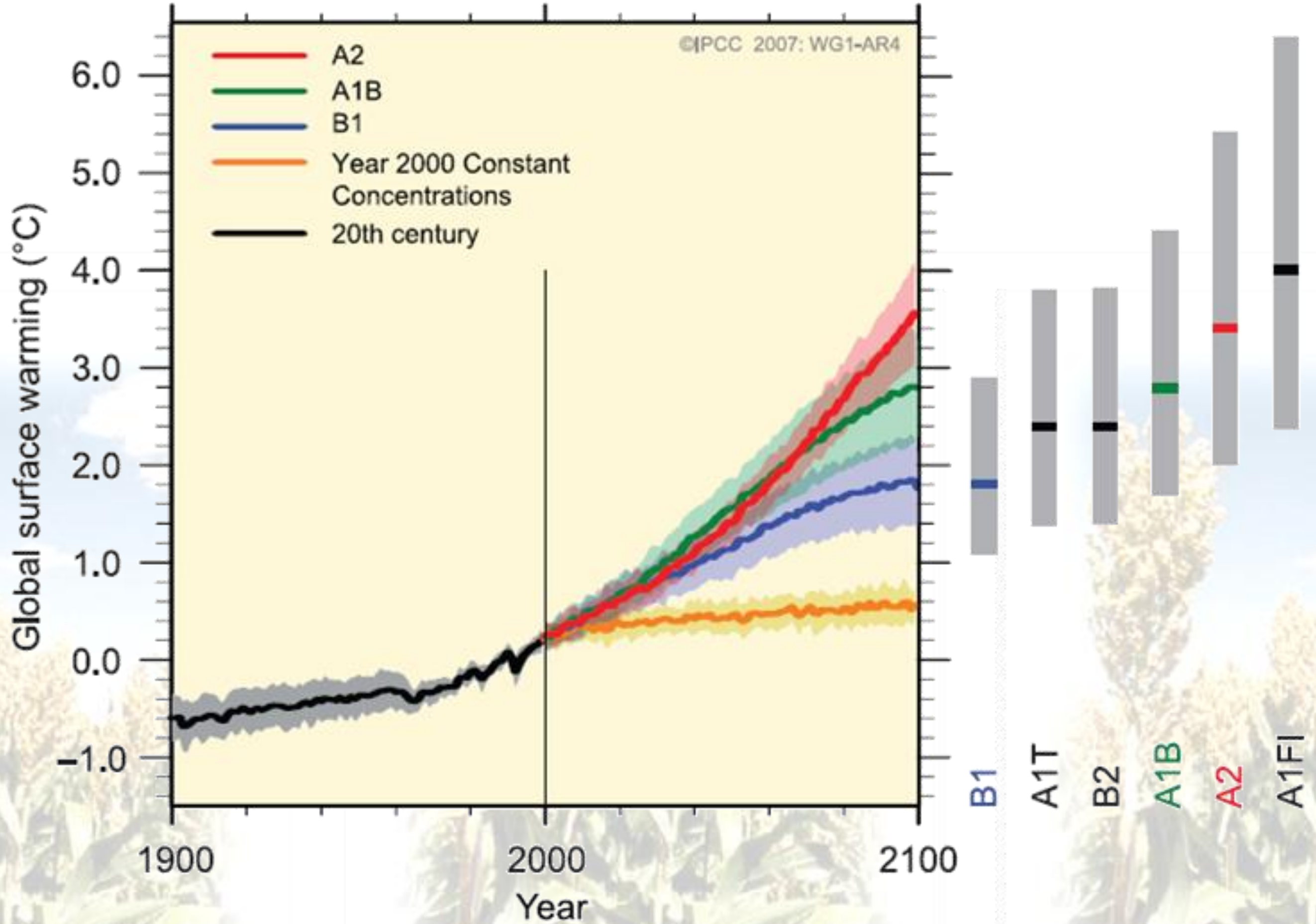


There are two General Circulation Models (3 sites) for El Salvador

Crop Simulation and Climate Model: Methods

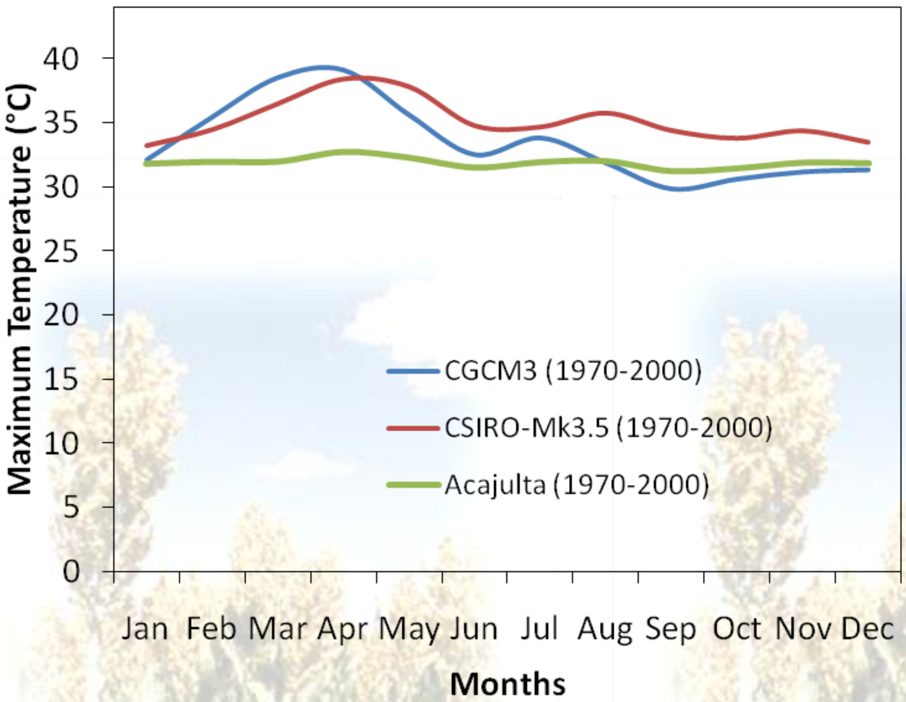
- Crop modeling was performed in DSSAT (Decision Support System for Agrotechnology Transfer) software suite.
- CERES-Sorghum and CERES-Maize and CROPGRO-Dry bean were used to simulate phenology and grain yield.
- Two Global climate models (GCM) used in this study were Canadian GCM (CGCM3.1 T47) and Australian 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)

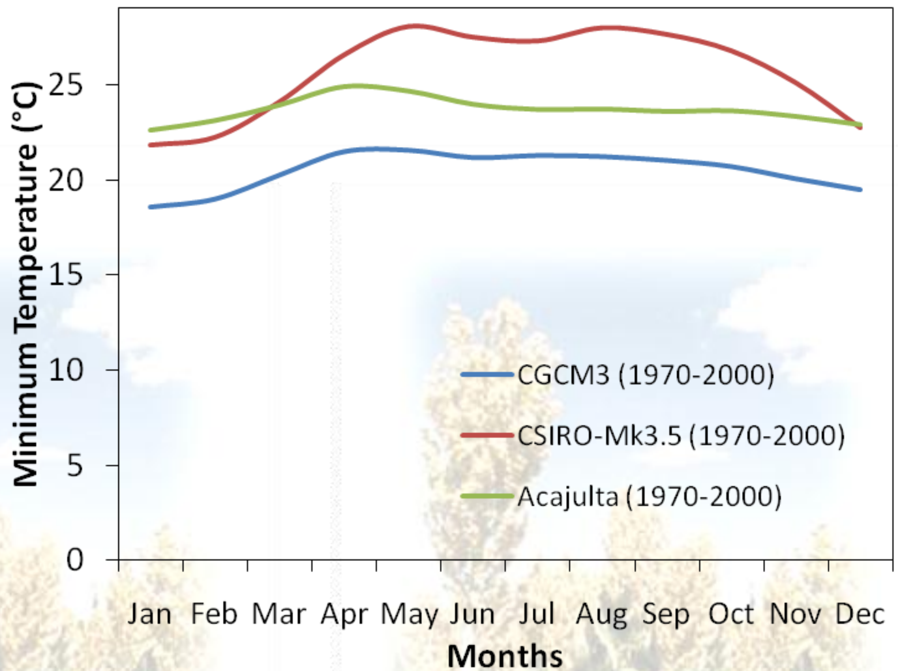
IPCC Scenarios Used for Simulations



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

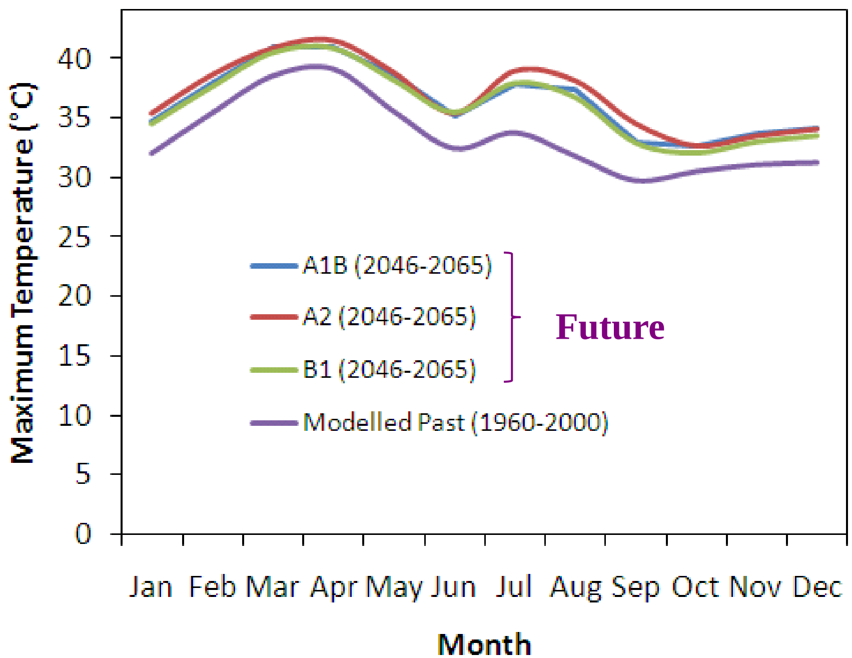
El Salvador: Model Uncertainties: Past



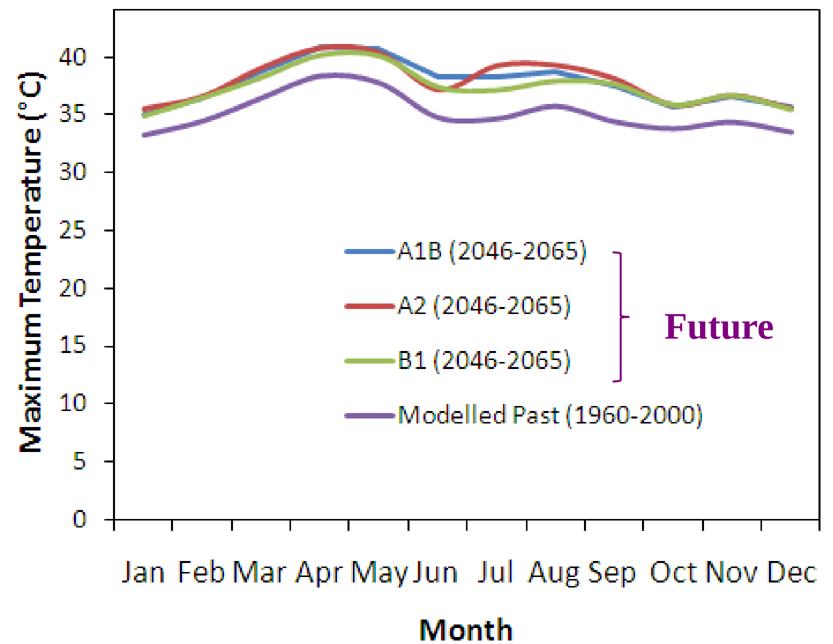


There are uncertainties in different models of past data (1970 - 2000) from Acajulta (El Salvador)

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



CGCM3.1 (T47)

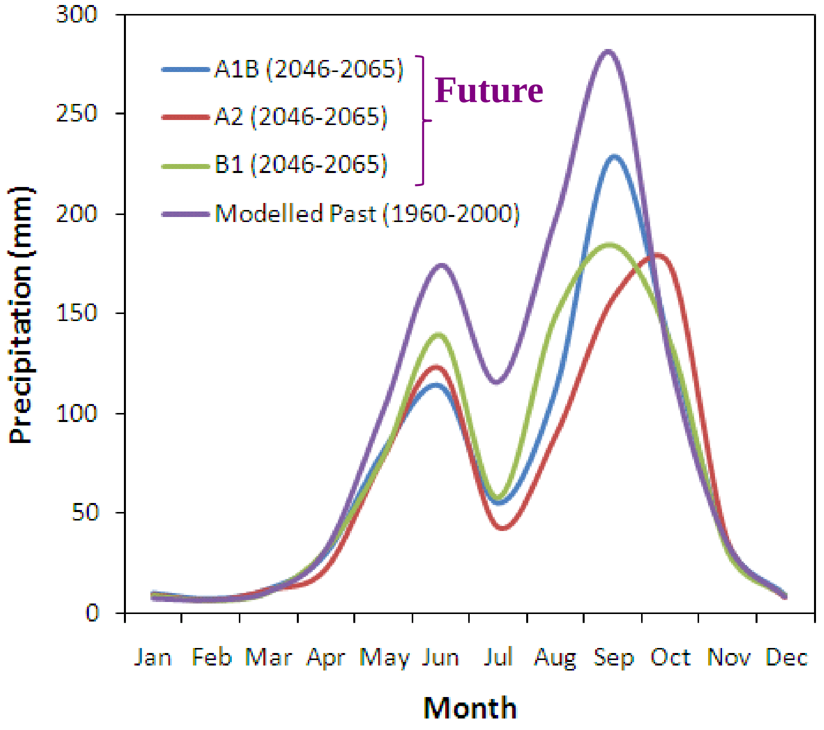


CSIRO-Mk3.5

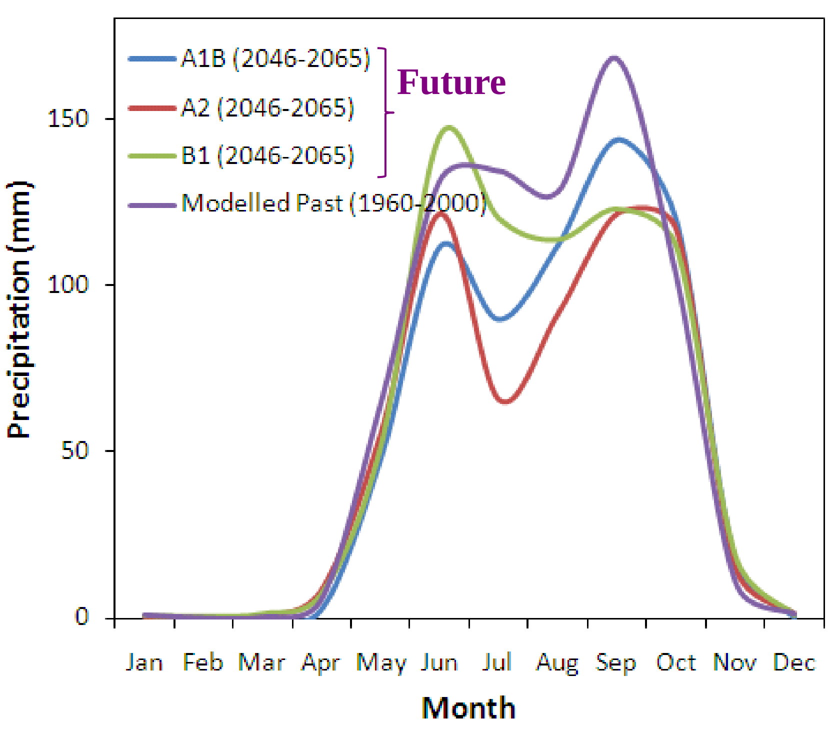
There are uncertainties in different emission scenarios and model predictions.

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)

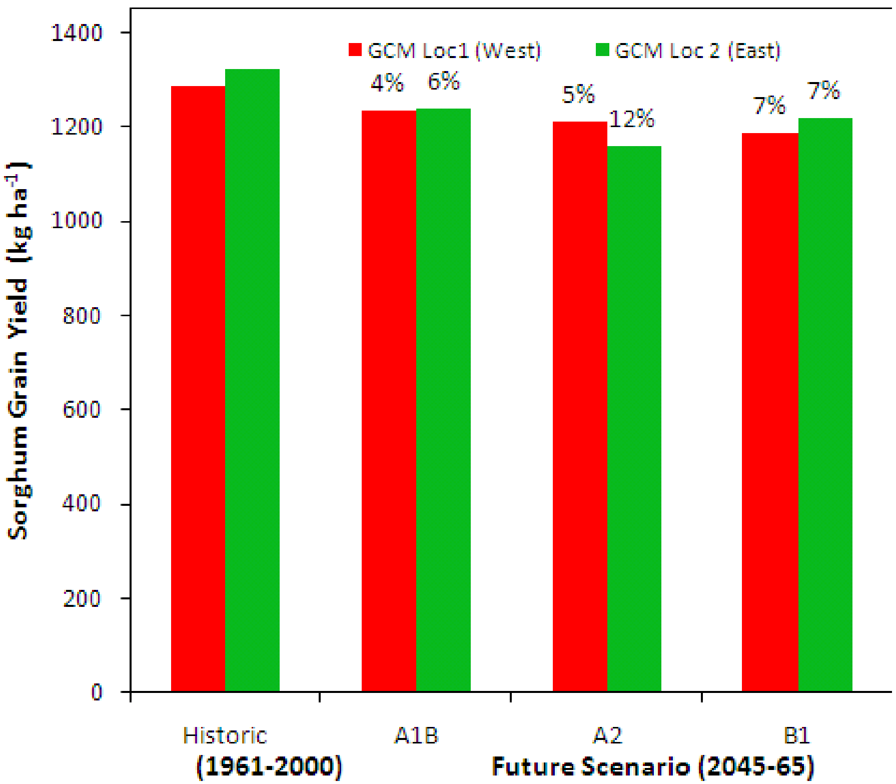


El Salvador: Grain Sorghum Model

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



CGCM3.1 (T47)

CSIRO-Mk3.5

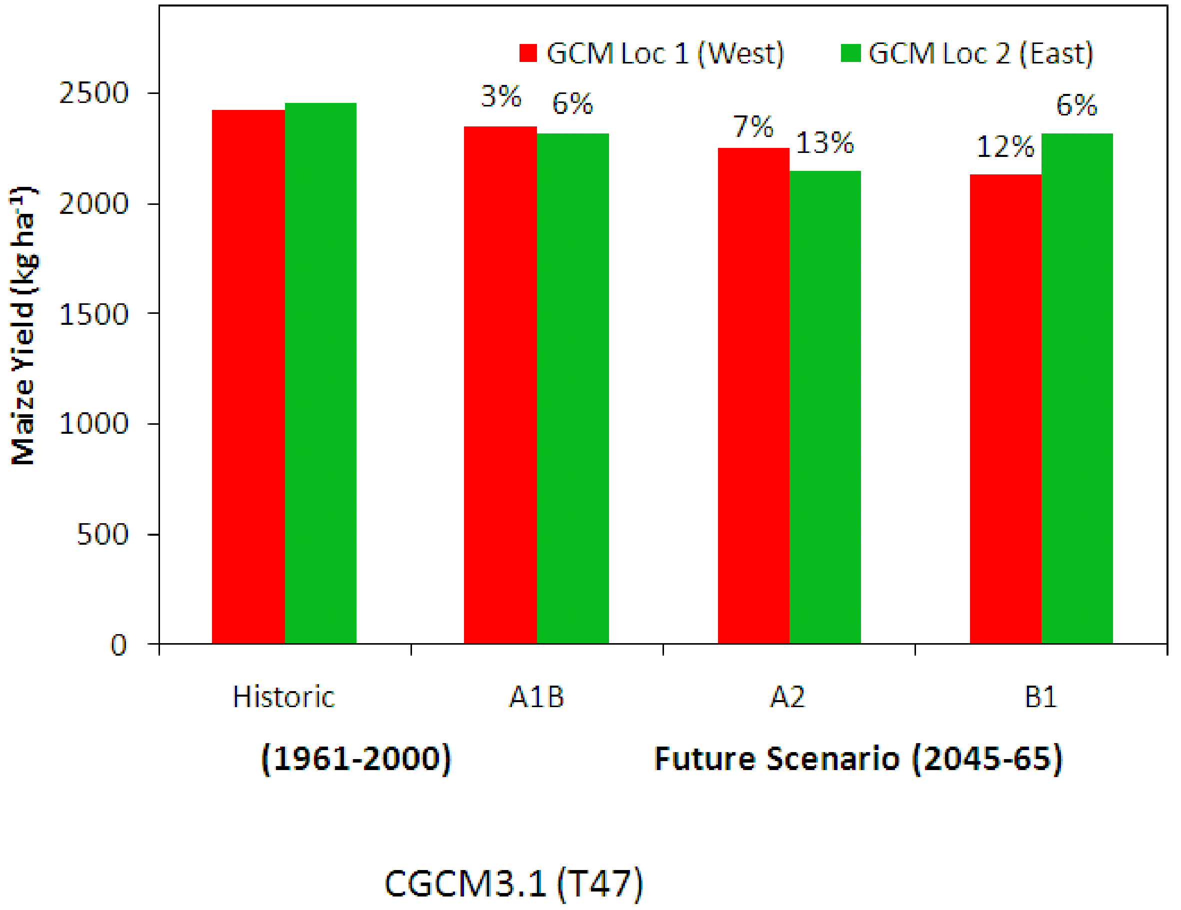
Models predict yield losses of 5 – 15%, in both eastern and western regions.

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



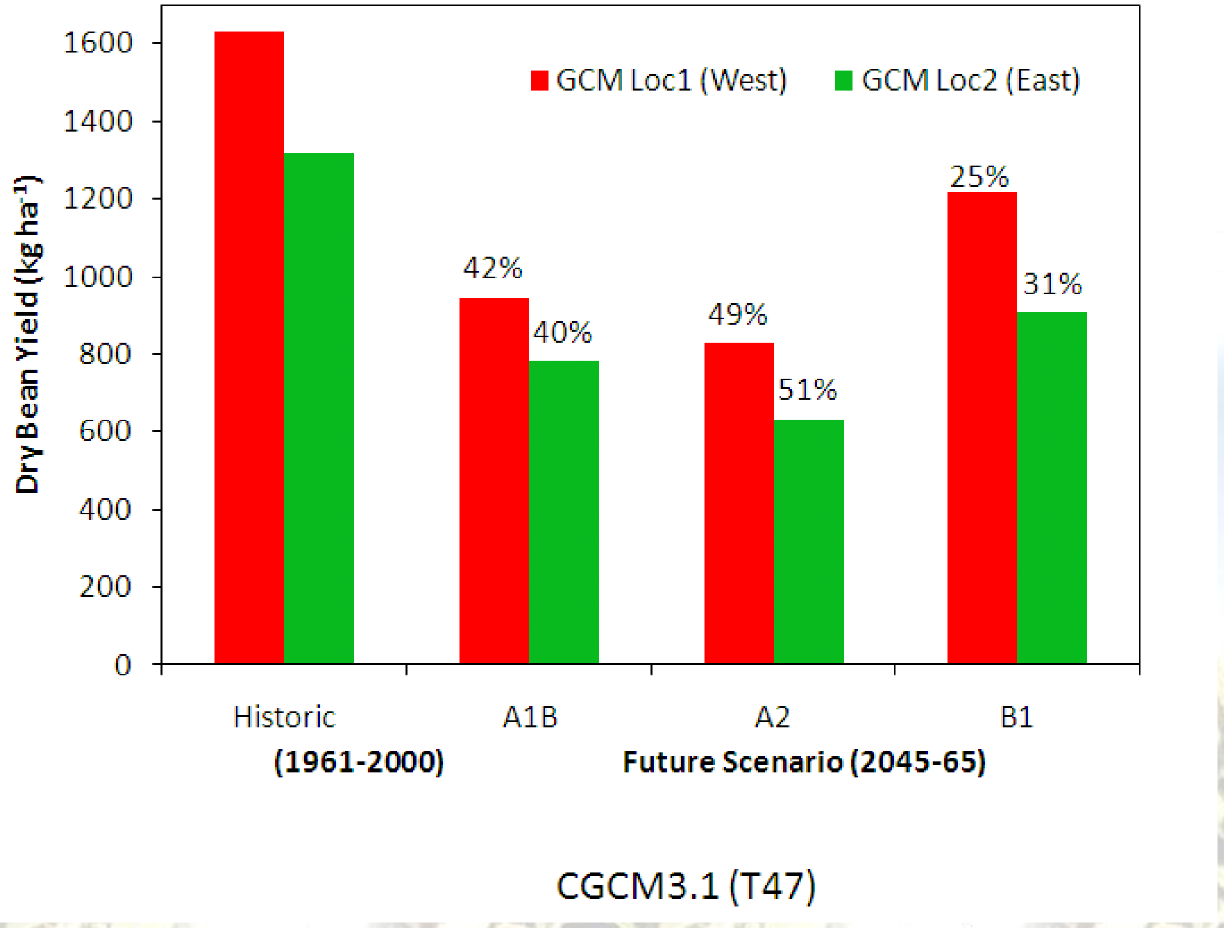
Models predict yield losses of 3 – 13%, in both eastern and western regions.

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"

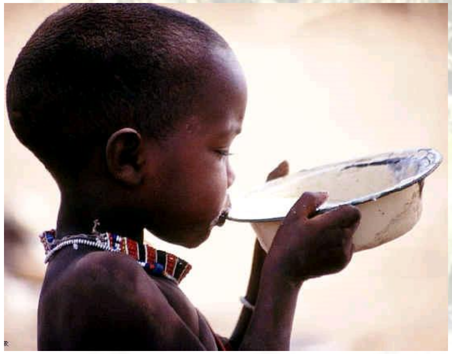
Norman E. Borlaug

(Nobel Peace Laureate)

"You cannot build peace on empty stomachs."

John Boyd Orr

(Nobel Peace Laureate
First FAO Director General)



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KANSAS STATE UNIVERSITY

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University of Florida

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