

Impacts of Present and Future Climate Variability on Agriculture and Forestry in the Temperate Regions

NORTH AMERICA



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Introduction

This paper focuses on the vulnerability of agriculture and forestry to climate variability and climate change in North America

Topics of Discussion

- 1. Agriculture in North America**
- 2. Climate of North America**
- 3. Agricultural Impact of Climate Variability in North America**
- 4. Agriculture's Role in Greenhouse Gas Emissions**
- 5. Scenarios of CO₂, Climate, and Agriculture**
- 6. Vulnerability of the Agricultural Sector**

Agriculture in North America (USA)

- **The United States is the world's fourth largest country. Nearly 30 percent of its territory (approximately 260 million hectares) is covered by forests.**
- **Over 25 percent (approximately 240 million hectares) is permanent grassland and other non-forested pasture and rangeland.**
- **Approximately 20 percent of the area (185 million hectares) in the United States is devoted to cropland.**

Agriculture in North America (USA)

- **Agriculture, including grazing lands and forested areas, represents nearly 75 percent of the total expanse of the highly industrialized United States.**

Agriculture in North America (USA)

- **While there have been declines in area devoted to crop production, U.S. harvests feed a population that has grown two and a half times in the last century, and its food exports have expanded considerably.**

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Agriculture in North America (USA)

- While there have been declines in area devoted to crop production, U.S. harvests feed a population that has grown two and a half times in the last century, and its food exports have expanded considerably.
- In 1900, 60% of the population was in rural areas; 6.4 million farms; and, average farm size was 60 hectares.
- In 1990, 25% of the population was in rural areas; 2 million farms; and, average farm size was 198 hectares.

Agriculture in North America (Canada)

- **Canada is the second largest country in the world and extends over 997 million hectares in total, of which 921.5 million hectares is land area.**

Agriculture in North America (Canada)

- **Large areas of the Prairies are devoted almost exclusively for crop production, while small pockets of concentrated livestock production exist in areas of British Columbia and southern regions of Alberta, Ontario and Quebec.**

Agriculture in North America (Canada)

- **With about 10 percent of the world's forests and nearly 25 percent of the planet's fresh water (much of it in the forested areas), Canada's forests play critical roles in moderating climate and filtering air and water.**

Agricultural Areas of Canada

Agricultural Areas of Canada



Cultivated	41.2
Pasture (tame/seeded)	4.3
Grassland	15.6
Other	6.9
Total	68.1 (10 ⁶ ha)

Farmland as a portion of land area in various parts of Canada in 1996 (F. Wang and D.B. Gleig, AAFC)

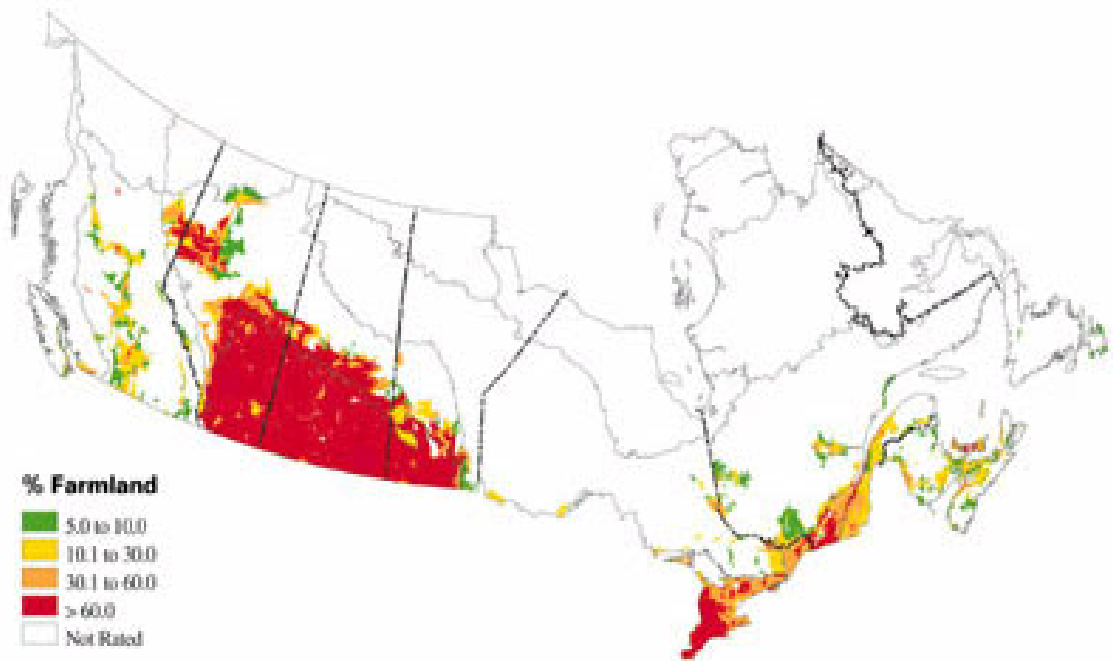


Figure 1: Iowa statewide temperatures during the growing season, April-September, Source: National Climatic Data Center / NESDIS / NOAA for 1895-2001.

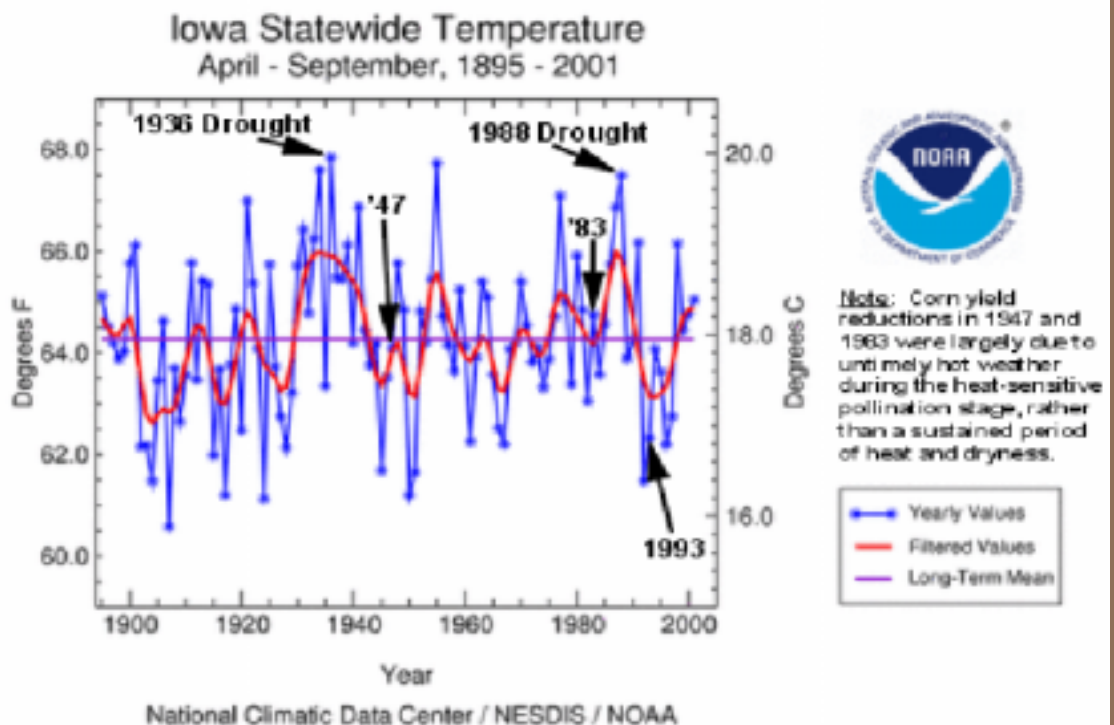


Figure 2: Iowa statewide precipitation during the growing season, April-September, for 1985-2001

Source: National Climatic Data Center / NESDIS / NOAA.

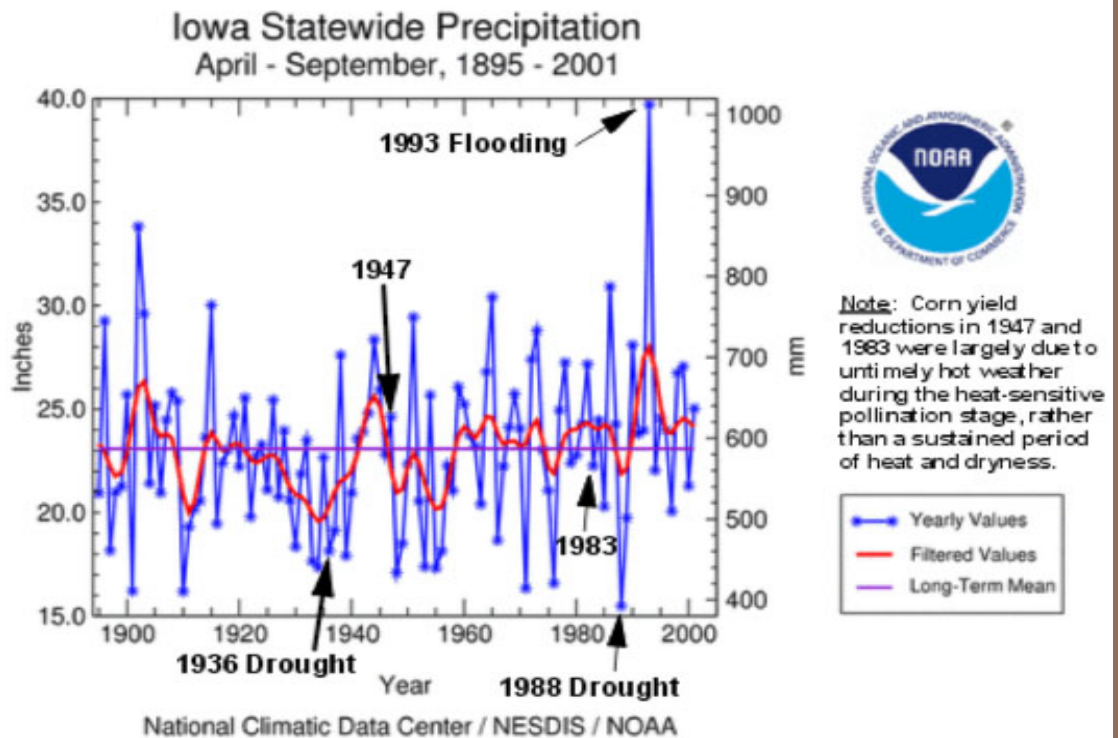


Figure 3: Annual national temperature departures and long-term trend: 1895-1996.

Source: CCS Summary 1997, p.6. .

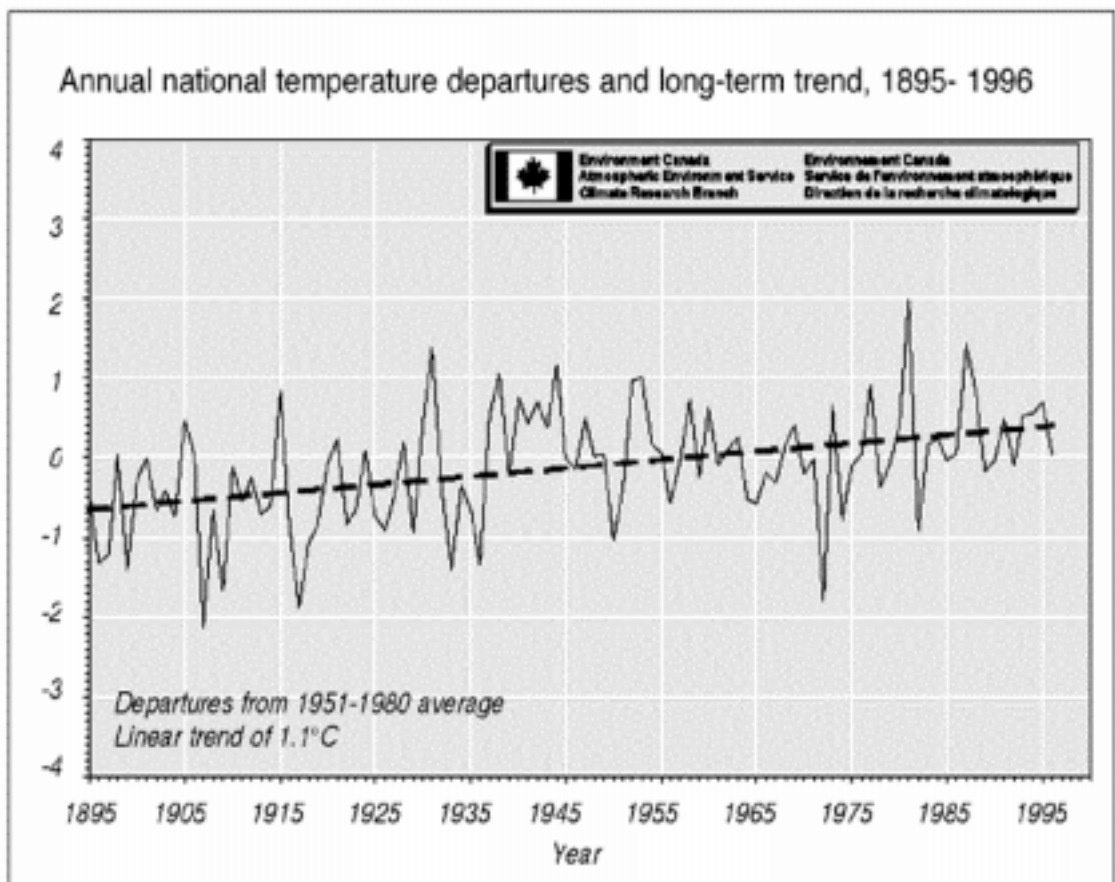
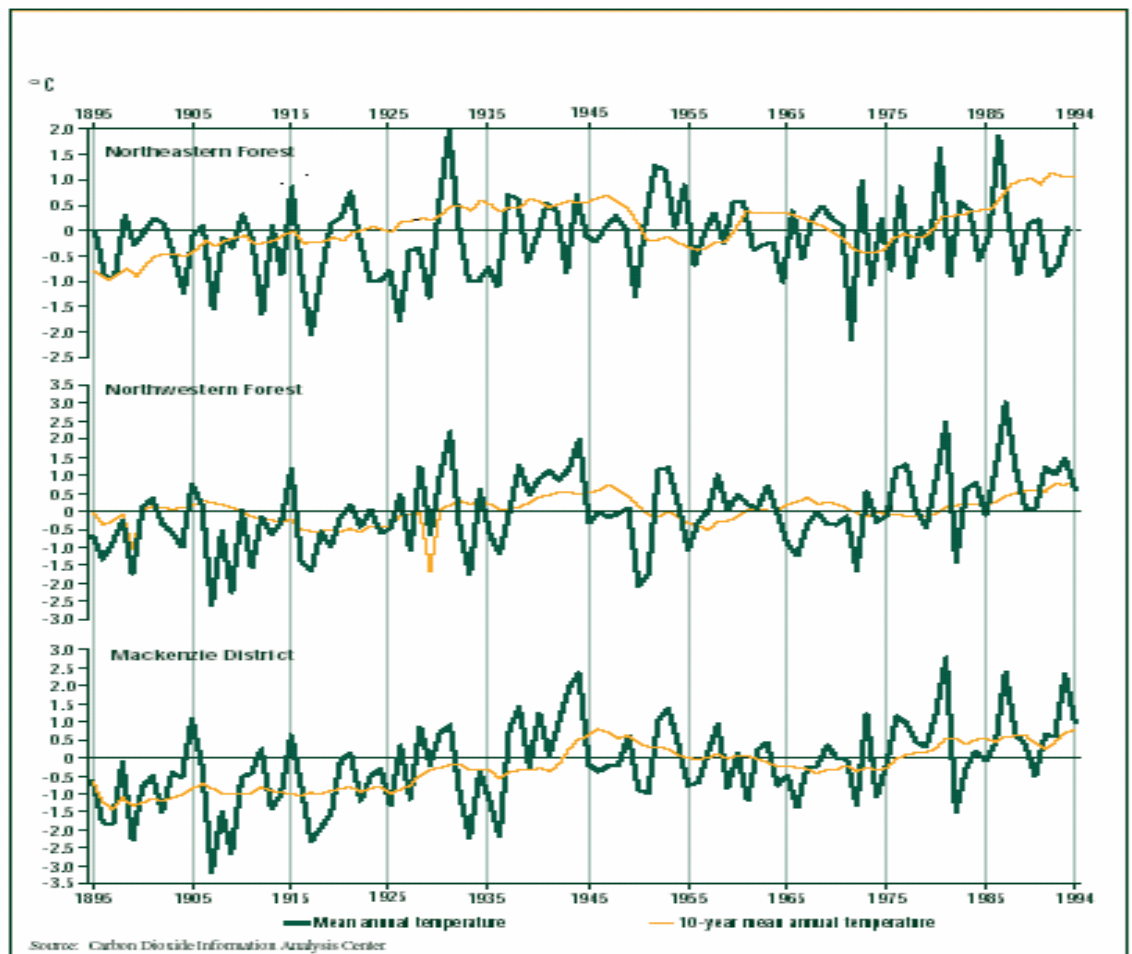


Figure 5. Temperature deviations in three regions of the boreal forest: 1985-1994

Source: Criteria and Indicators, Progress to data, Criterion 2: Ecosystem Condition and Productivity, Element 2.1: Disturbance and Stress, p. 36, Canadian Council of Forest Ministers, 2001.

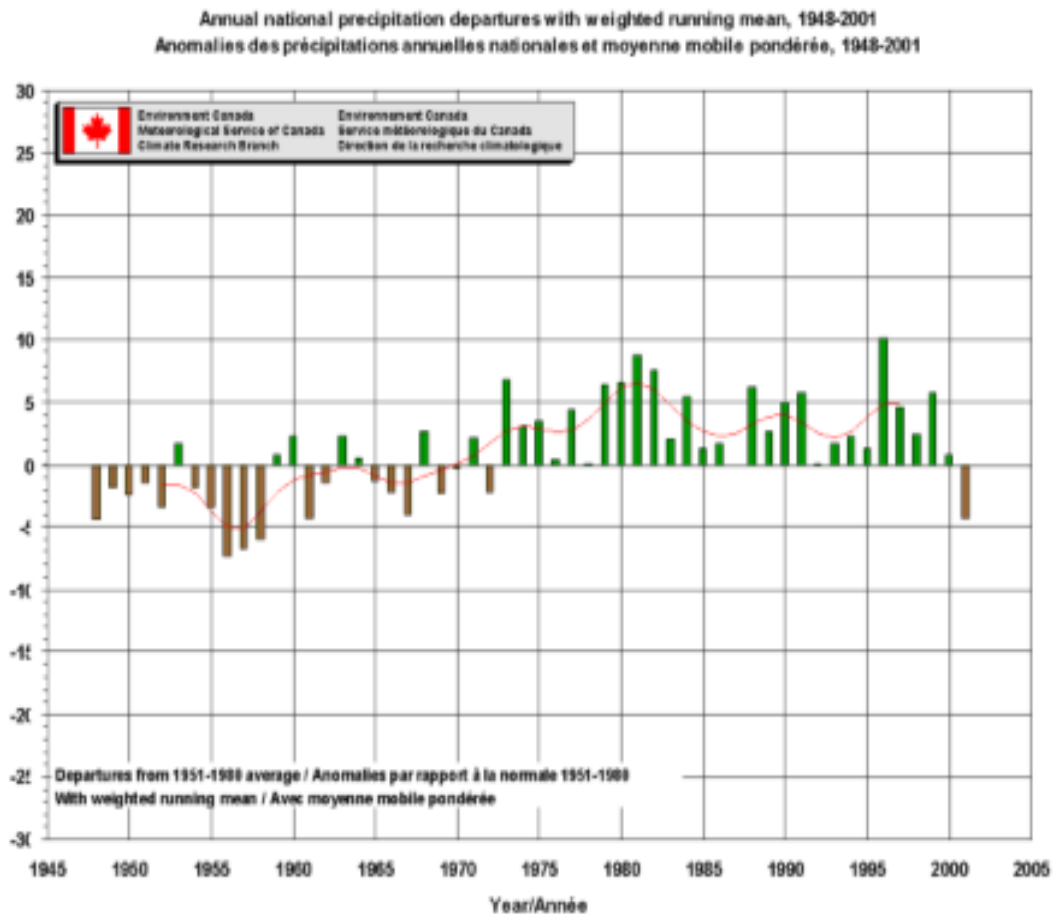


Disturbance and stress

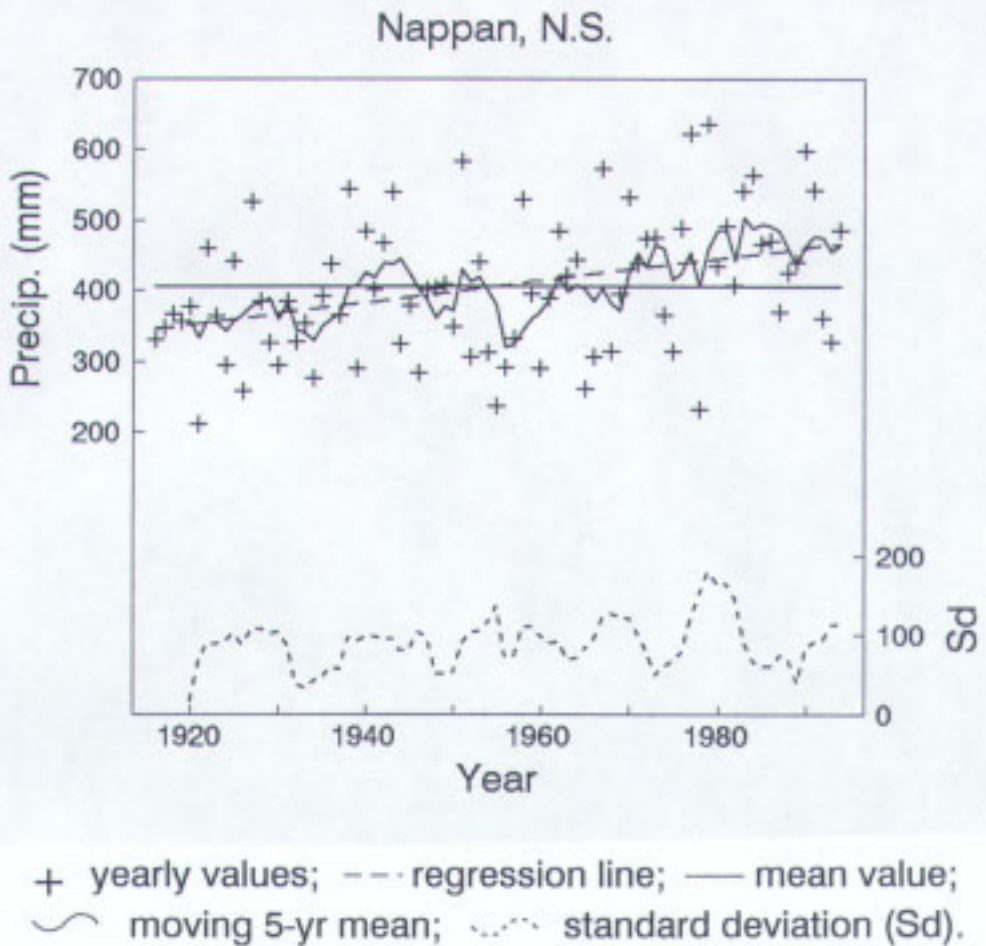
Ecosystem condition and productivity

Figure 4: Annual national precipitation with weighted running mean: 1945-2001.

Source: Climate trends and variations bulletin for Canada, Annual 2001 temperature and precipitation in historical perspective, p.3. Environment Canada, Meteorological Service of Canada, Climate Research Branch.



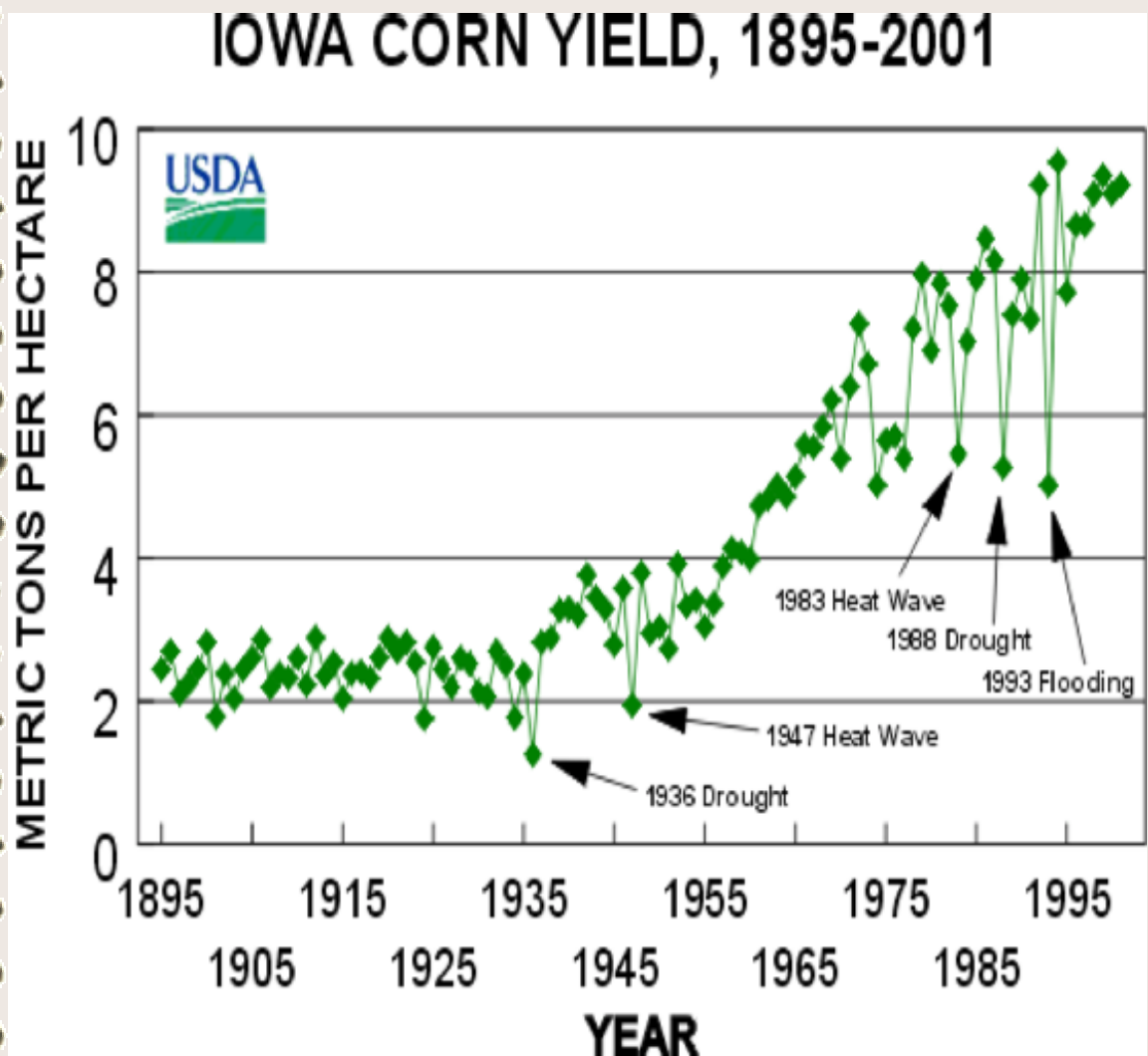
Long term trends in May-Sept. precipitation at Nappan, N.S., Canada



Source: A. Bootsma, Eastern Cereal
and Oilseed Research Centre,
Agriculture and
Agri-Food Canada, Ottawa, Canada

**Figure 6: Iowa state corn yields
(metric tons per hectare)
for 1895-2001.**

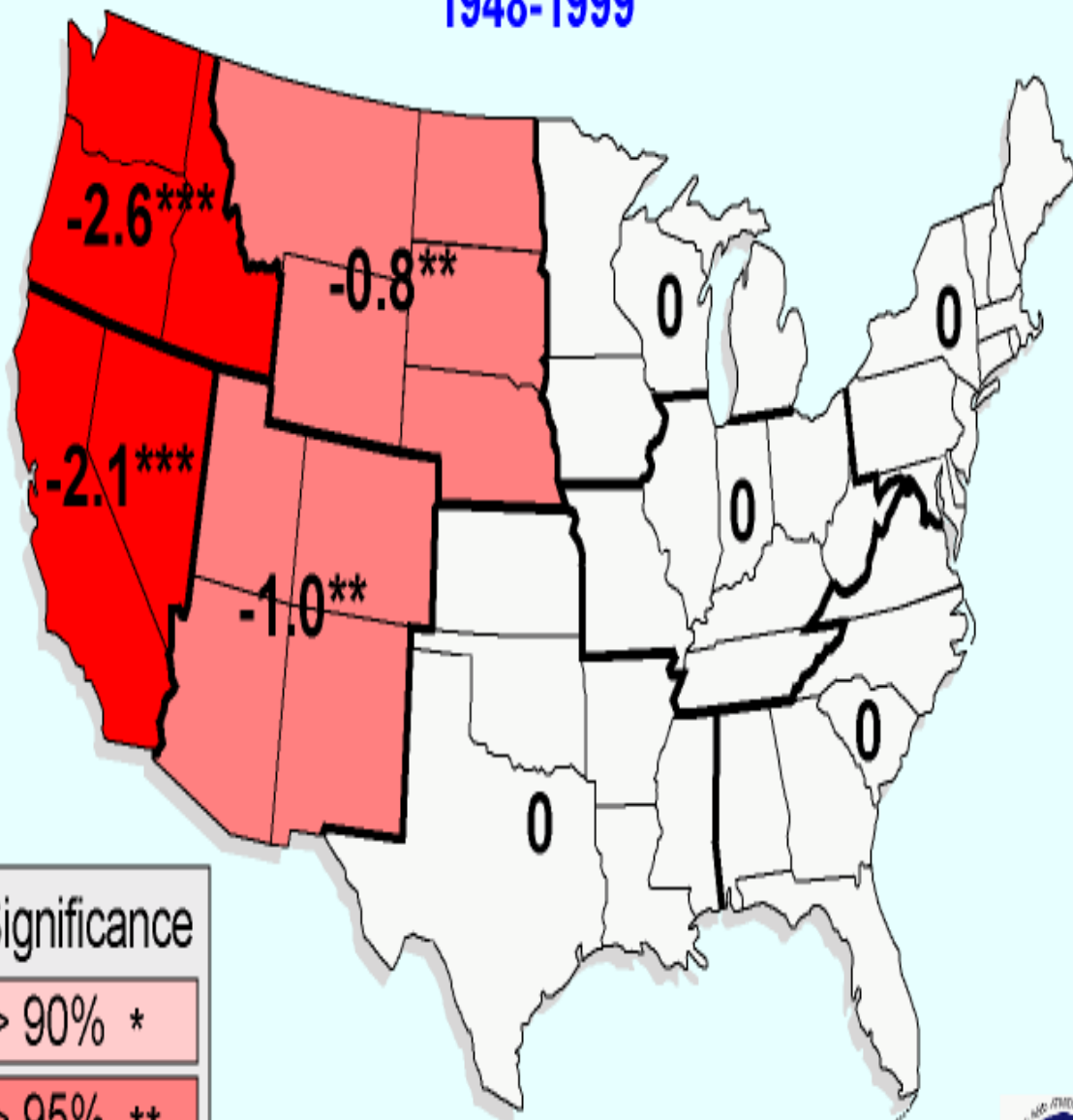
Source: United States Department of Agriculture.



ANNUAL NUMBER OF FROST DAYS

TRENDS IN DAYS PER DECADE

1948-1999



Significance

> 90% *

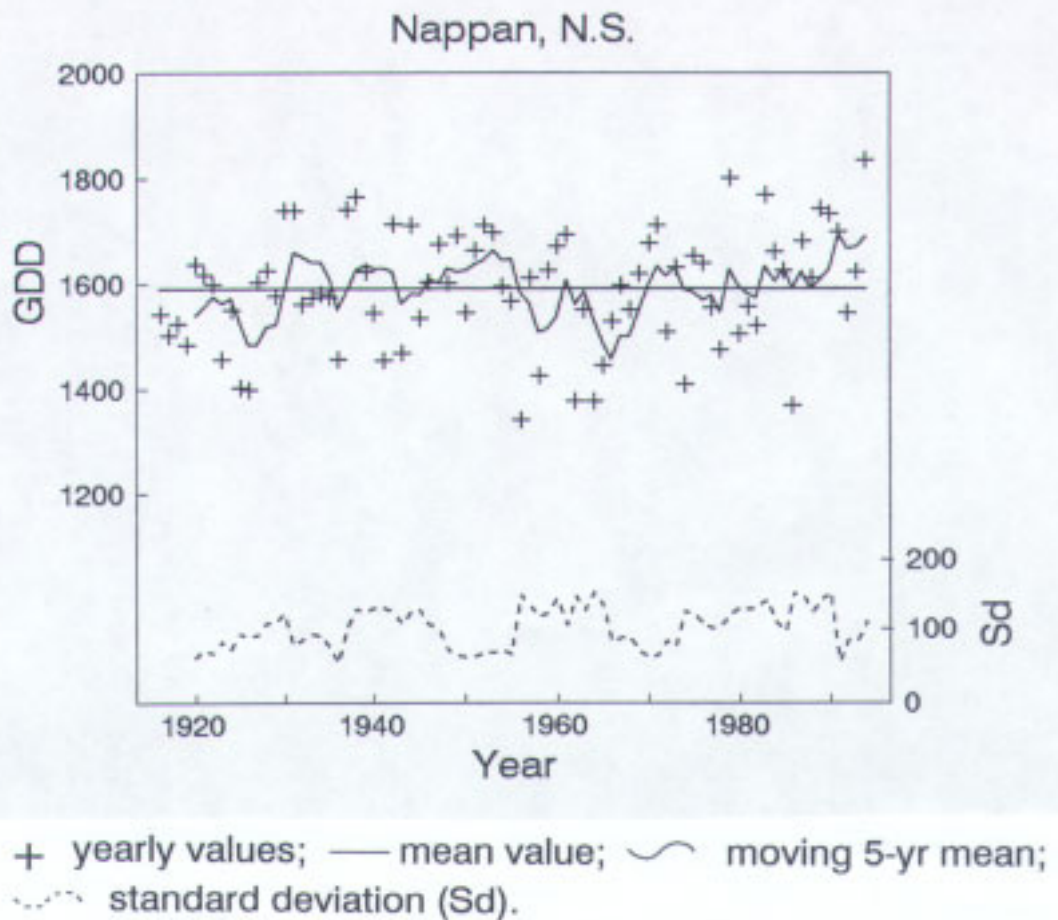
> 95% **

> 99% ***

All U.S. = -0.8**



Long term trends in Growing Degree-Days > 5 C at Nappan, N.S. Canada



Source: A. Bootsma, Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, Canada

Summary and Conclusions

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- Key issues for agriculture are extreme weather events, such as drought, flooding, and heat waves.
- **Changes in drought tendencies, soil moisture availability, and frost-free growing seasons are also big factors that influence agricultural and forest productivity.**

Agriculture's Role in Greenhouse Gas Emissions

- The clearing of forests, the draining of wetlands, and the plowing of prairies have led to a significant increase in atmospheric CO₂ as organic carbon was decomposed.
- Nitrous oxide (N₂O) originates as a byproduct of N fertilizer application and in water-logged soils. Thus, in higher latitudes, a spring burst of N₂O occurs with snowmelt. Heavy rains in low-lying areas also cause a N₂O burst.
- Methane (CH₄) emitted from agriculture is produced by the microbial breakdown of plant material. Normally, C in decomposing plant material converts to CO₂. If oxygen is absent, C is released as CH₄ (digestive system of cattle, water-logged rice paddies and wetlands).

Agriculture's Role in Greenhouse Gas Emissions

- **N₂O is a potent gas with about a 120 year lifetime in the atmosphere. Its potential warming is about 300 times that of CO₂ over 100 years. N₂O also eventually converts to NO in the upper atmosphere, which breaks down the all-important ozone.**
- **CH₄ has about 20 times the warming effect of the same amount of CO₂ over a 100 year period. Chemical reactions convert CH₄ to CO₂ in the atmosphere. However, the average lifetime of CH₄ emitted into the atmosphere is about 12 years.**

Trends in U.S. Greenhouse Gas Emissions (MMT carbon equivalents)

• Category	1990	1996
CO2		
Fossil fuel combustion	1,330	1,450
Other industrial sources	20	20
• CH4		
Transportation and industry	60	60
Land use and agriculture	50	50
Landfills and waste	60	70
• N2O		
Transportation and industry	30	30
Land use and agriculture	65	70
• HFCs, PFCs, SFs	20	35
• Total	1,635	1,785

Source: U.S. Environmental Protection Agency

Table 1: Estimates of total greenhouse gas emissions from Canada's agro-ecosystems

	1981	1986	1991	1996	2000*	2005*	2010*
	(Tg CO ₂ equivalents)						
CO ₂	9	7	5	3	1	0	0
CH ₄	22	20	20	23	23	24	25
N ₂ O	32	33	34	41	43	45	48
Total	63	60	59	67	67	69	73

* Predicted using a scenario of medium growth from Canadian Regional Agricultural Model (CRAM) to 2007. All 2010 data follow a best-fit trend using data from 1993 to 2007 from the CRAM. All fertilizer data were predicted using a best-fit trend from 1981, 1986, 1991, and 1996 Census data. All sheep, chicken, and turkey populations were predicted using a best-fit trend from Census data. (R. L. Desjardins, AAFC).

Canada's total greenhouse gas emissions are increasing

Projected effects of various agricultural practices that affect greenhouse gas emissions

Effect on GHG emission				Other considerations			
Practice	CO ₂	CH ₄	N ₂ O	Feasibility	Economics	Soil quality	Environment
Reduced tillage intensity	++	0	?	+++	+	++	++
Reduced summer fallow area	+++	+	-	++	-	++	+
Improved manure management	0	+	++	++	--	+	++
Improved feeding rations	-	++	0	+	++	0	0
Improved drainage/irrigation	+	+	++	+	+	+	-
+beneficial 0=neutral - =detrimental							

Source: The Health of our Air, Table 16. Janzen et al., 1999

Greenhouse gas emissions from agriculture: Conclusions

Conclusions

- Farms account for about 10% of Canada's greenhouse gas emissions
- About 2/3 of the emissions are from N_2O
- About 1/3 are from CH_4
- Livestock and manure account for about 58%
- Cropping practices account for about 37%
- Net release of gases (N_2O , CO_2 , CH_4 and NH_3) is usually a symptom of inefficiency
- Agriculture will always be a source of CH_4 and N_2O but reductions of 20 - 30 % may be possible
- Agricultural soils, as a carbon sink, have a substantial potential to help Canada reduce its GHG emissions

Agriculture's Role in Greenhouse Gas Emissions-Mitigation

- **Atmospheric CO₂ can be returned to the land by afforestation of formerly plowed land, conservation tillage by a cover crop as well as no-till conservation practices, and higher-yielding crops.**
- **Soil microorganisms can remove both NO₂ and CH₄ from the air with improved pasture conditions and cover crops on cultivated land to lower the amount of inorganic nitrogen in the soil.**
- **Higher quality cattle feeds can reduce CH₄ emissions from domestic livestock.**

• **Source: Agriculture: The Potential Consequences of Climate Variability and Change for the United States.**

J.M. Reilly, Cambridge University Press. 2002

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Summary and Conclusions

- Agriculture plays a role in the inventory of greenhouse gases and in mitigation measures to reduce these gases.
- Rapid shifts in the agricultural land base caused by extreme climatic variability can severely disrupt rural communities and associated infrastructures.
- **It is essential that proactive mitigation measures be developed to cope with these changes to preserve agricultural and forest systems.**

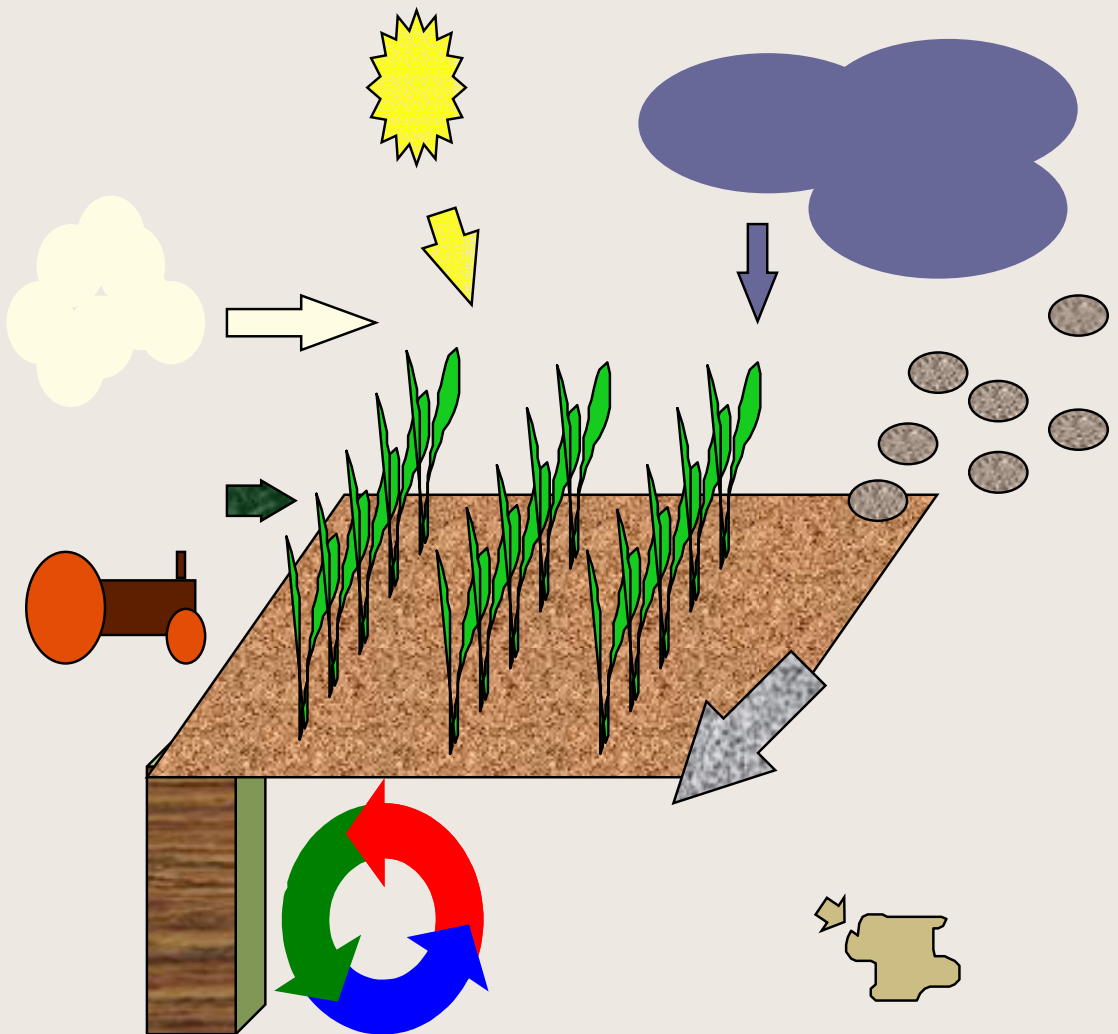
EPIC Simulation Model

- **A comprehensive agro-ecosystem model capable of describing the behavior of crops.**
- **EPIC contains routines to handle CO₂ fertilization, water balance, wind and water erosion, nutrient application and leaching, tillage practices, and soil density changes.**

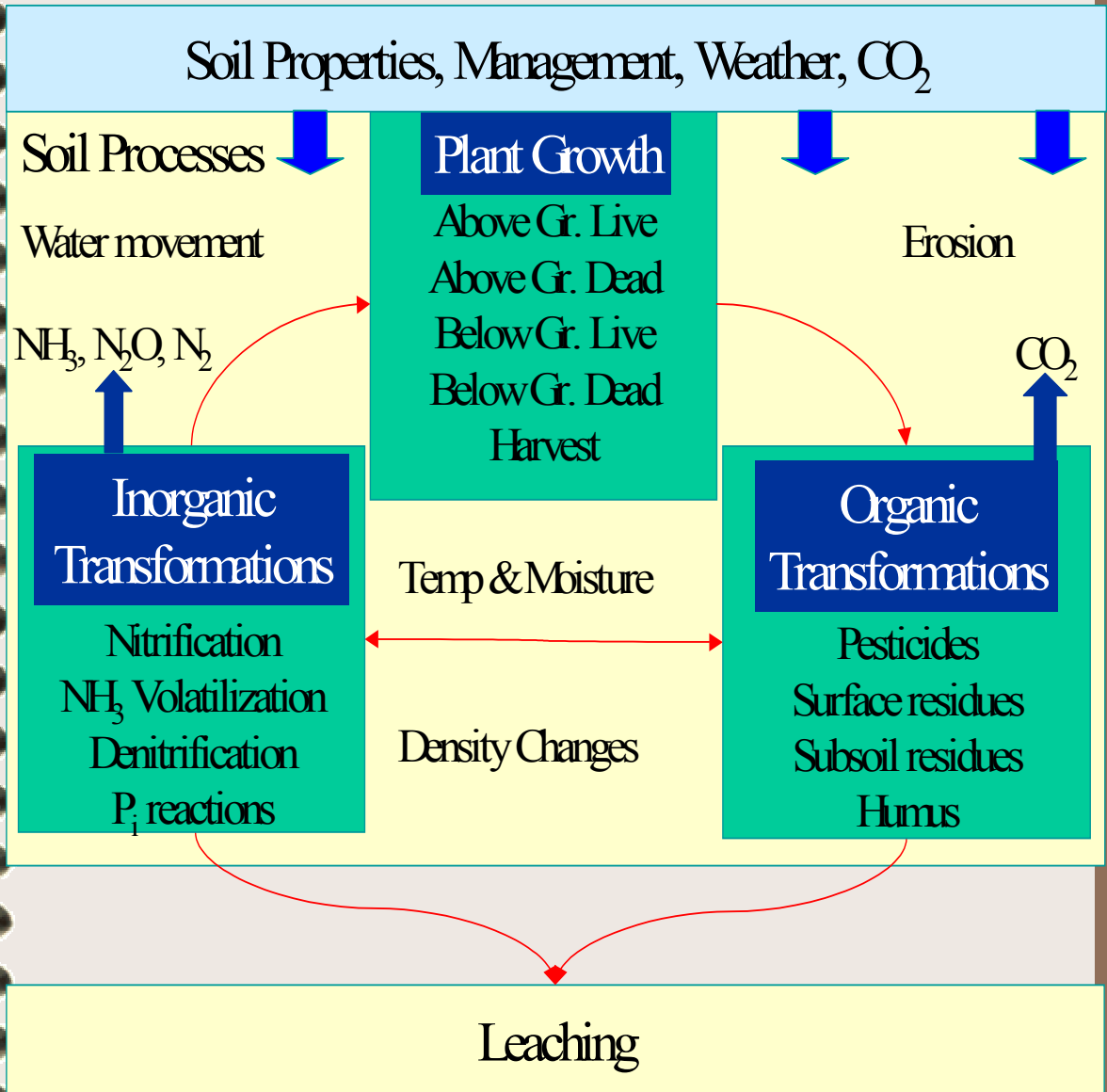
The EPIC model – a quick overview

- **Widely Tested And Adapted**
- **Multiple Crops**
 - 100 crops, up to 12 plant species in a field
 - Complex rotations and tillage operations
- **CO₂ fertilization effects on plant growth and water use**
- **Hydrological Balance**
- **Soil Density Changes**
- **Tillage, Erosion, Leaching**
- **Tillage model**
 - Mixes nutrients and crop residues within plow depth
 - Simulates changes in bulk density
 - Converts standing residue to flat residue
 - Determines ridge height and surface roughness

The EPIC model – a quick overview



The EPIC model – a quick overview



EPIC Simulation Model

- **EPIC (version 5300) integrates the major processes that occur in the soil-crop-atmosphere management system, including hydrology, weather, wind and water erosion, nutrient cycling, plant growth, soil temperature, tillage, plant environmental control and economics.**
- **Under a warmer and slightly wetter 2xCO₂ climate scenario, the planting dates advanced 1 to 2 weeks in eastern and central Canada and by approximately 3 weeks in western Canada.**

EPIC Simulation Model

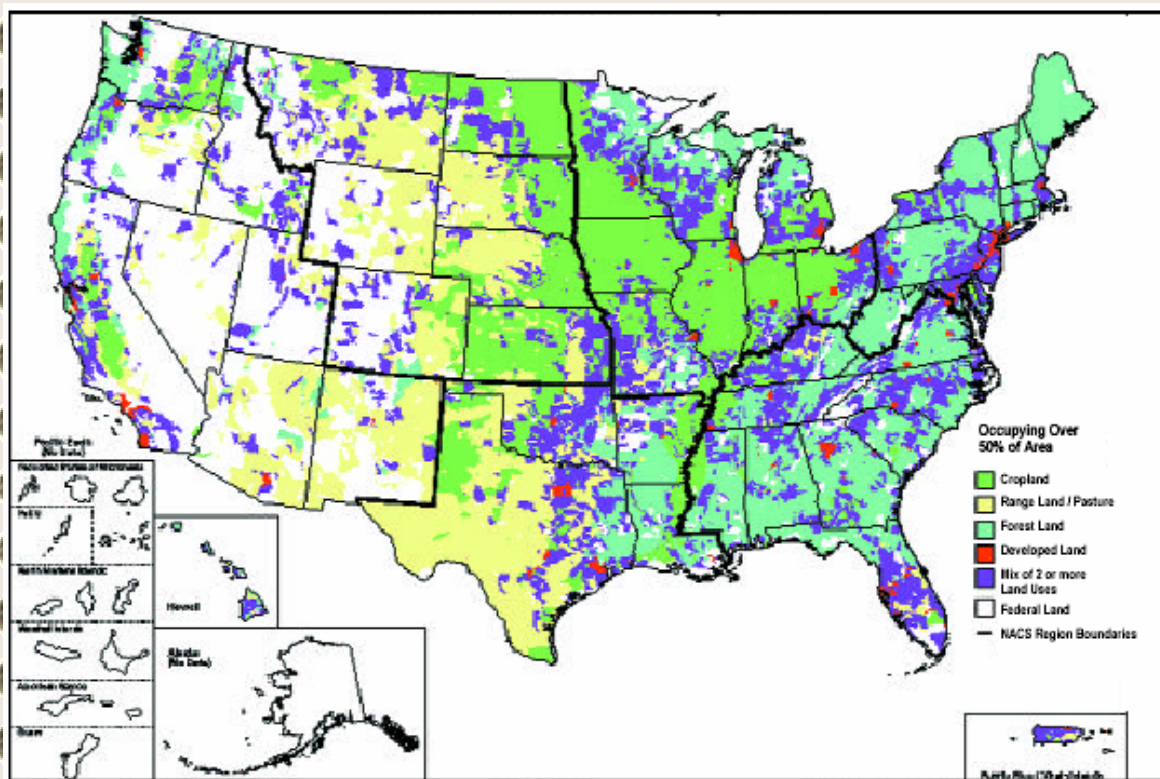
Summary of crop yields and standard deviations as simulated by EPIC for baseline (1966-1995 period) and a future climate scenario (2041-2060 period) for selected locations in Canada.(Table 2)

Crop	# sites	Yields (t/ha)			
		Average		Std. Dev.	
		Baseline	2xCO ₂	Baseline	2xCO ₂
Barley	29	3.5	3.5	0.77	0.94
Spring wheat	25	2.8	2.7	0.85	0.91
Canola	12	2.5	2.6	0.89	1.03
Corn	6	5.7	5.0	1.73	1.99
Soybeans	6	2.0	2.2	0.56	0.83
Potatoes	5	6.7	7.9	0.81	1.01
Winter wheat	3	3.5	4.2	0.67	0.77

Source: Results were extracted by A. Bootsma from De Jong, R., Li, K.Y., Bootsma, A., Huffman, T., Roloff, G. and Gameda, S. 2001. Crop yield and variability under climate change and adaptive crop management scenarios. Agriculture and Agri-Food Canada, Eastern Cereal and Oilseed Research Centre, Ottawa, Ontario, Climate Change Action Fund Project A080, Final Report. 49 pp.

EPIC Simulation Model

- **Based on the assumption that at least 2400-2500 Crop Heat Units must be available for the crop to mature, corn and soybeans could be grown under the 2xCO₂ climate scenario at all locations (29 climate stations in 17 eco-regions selected across Canada) - except some of the most northern ones.**
- **When water stress was not a limiting factor, corn and soybean yields were comparable to those currently grown.**
- **The temporal yield variability of all crops increased under the 2CO₂ scenario from 6% for spring wheat to 50 % for soybeans.**



CLIMATE CHANGE MODELS

- **Canadian Model, developed at the Canadian Centre for Climate Modeling and Analysis.**
- **Hadley Model, developed by the Hadley Centre in the United Kingdom.**
- **Physical principles driving these models are similar, and both incorporate similar assumptions of mid-range future emissions in their scenarios.**

Model Assumptions

- **Soil nutrients are not limiting, and pests, insects, diseases, and weeds pose no threat to crop growth and yield.**
- **Positive crop responses to elevated CO₂, which accounts for 1/3 to 1/2 of the simulated yield increases, are considered as upper limits to actual responses in the field.**
- **Models' inability to predict the negative effects of excess water conditions on crop yields; thus, positive responses may be overestimated.**

CLIMATE CHANGE MODELS

- **On average over the United States in the 21st century:**
- **The Canadian model projects a greater increase in temperature than does the Hadley model.**
- **The Hadley model projects a much wetter climate than does the Canadian model.**

Temperature Trends & Projections

- **Temperatures have increased over the past century by 0.6 C, with the largest seasonal warming occurring in winter.**
- **Hadley model projects a 2-4 C increase over the next century while the Canadian model projects a 3-5.5 C rise.**
- **Largest temperature increases are expected over the South.**
- **Seasonal patterns indicate largest projected change in winter at night.**

Precipitation Trends & Projections

- **Average U.S. precipitation increased by 5-10% over the last century, due mostly to an increase in frequency and intensity of heavy rainfall.**
- **Hadley model projects increased precipitation over nearly the entire nation for the 21st century.**
- **Canadian model projects increases in the West, but decreases east of the Rockies and the southern half of the nation.**

Soil Moisture Patterns

- **Differences in the models accentuate soil moisture projections which reflect both changes in precipitation and evaporation.**
- **Canadian model indicates soil moisture decreases of more than 50% in the Central Plains (precipitation down 20%; temperature up 5.5 C). In contrast, Hadley model projects a soil moisture increase in this region (precipitation up 20%; temperature up 3 C).**
- **A key factor is how much temperatures rise even with increased rainfall!**

Drought Tendencies

- **Canadian model projects a nationwide drought problem, with intense drought tendencies in the Great Plains and Southeast.**
- **Hadley model also indicates increased drought tendencies in the Great Plains, but decreased tendencies in the Southwest and East.**

Scenarios of CO₂ , Climate and Agriculture (CO₂ Fertilization Effect)

- **Greater concentrations of CO₂ generally result in higher net photosynthetic rates. The photosynthetic rate is enhanced as additional carbon is available for assimilation. Thus, productivity and yields may rise.**
- **The actual response to CO₂ changes differ among crops. In the United States, wheat, rice, barley, oats, potatoes, and most vegetable crops tend to respond favorably, with a doubling of CO₂ increasing yields by 15 to 20%. Warm-season crops, including corn, sorghum, sugar cane and tropical grasses increase yields by only 5% with a doubling of CO₂.**
- **Crop productivity is limited by factors other than CO₂, such as nutrients and water, however.**
- **Source: A Review of Impacts to U.S. Agricultural Resources, R.M Adams et al., prepared for the Pew Center on Global Climate Change. 1999.**

Crop Yield Scenarios

- **Hadley and Canadian models used to project crop yields for two time periods, 2030 and 2090, for both dryland and irrigated crops. Models also considered responses to on-farm adaptation option for changes in planting dates and changes in varieties as well as “no adaptation” option.**
- **Both crop models assume the CO₂ fertilization effect with sufficient nutrients and water to support the projected yield increases.**

Figure 1a - Dryland Yields Without Adaptation

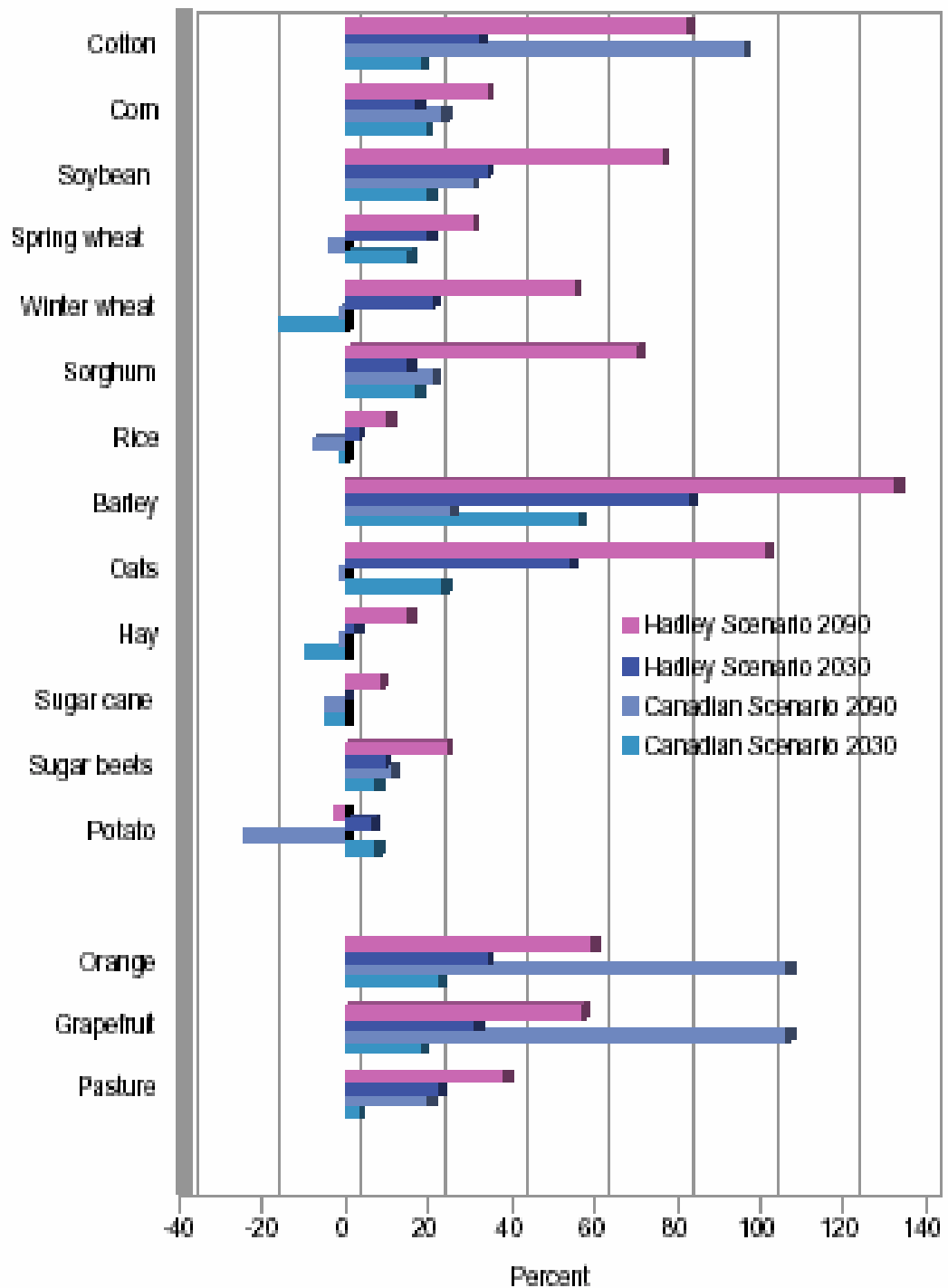


Figure 1b - Dryland Yields With Adaptation

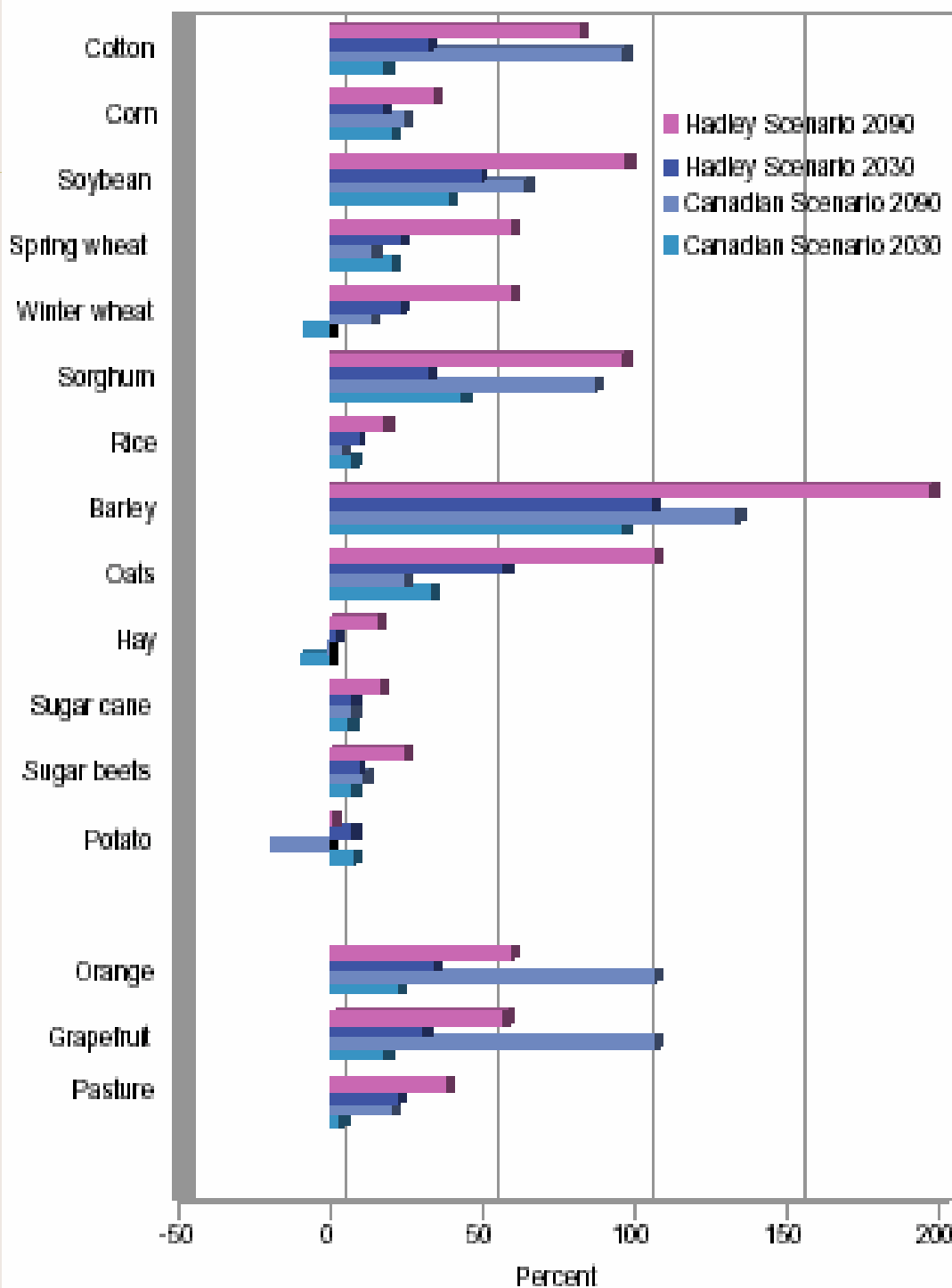


Figure 1c - Irrigated Yields Without Adaptation

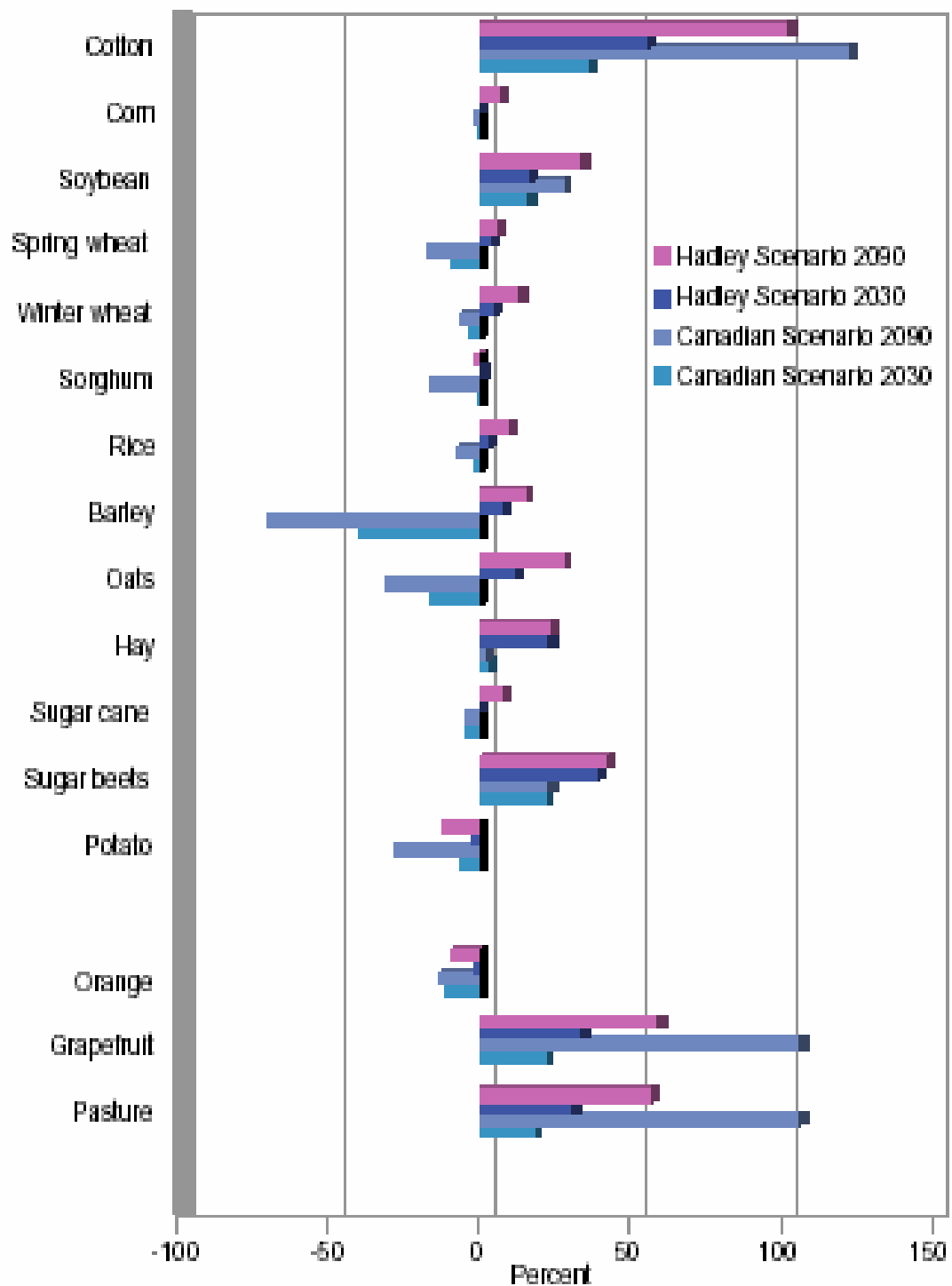


Figure 1d - Irrigated Yields With Adaptation

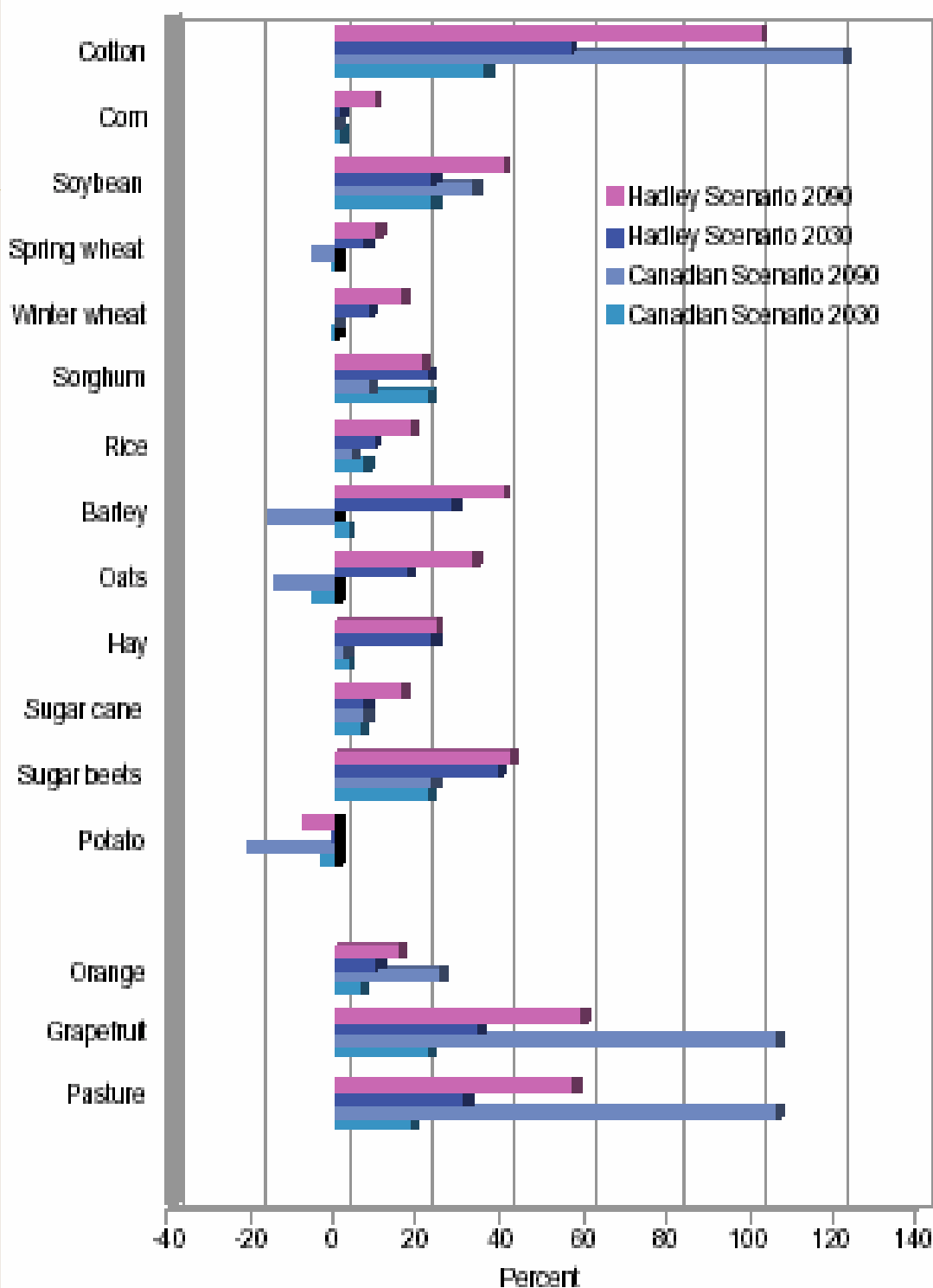
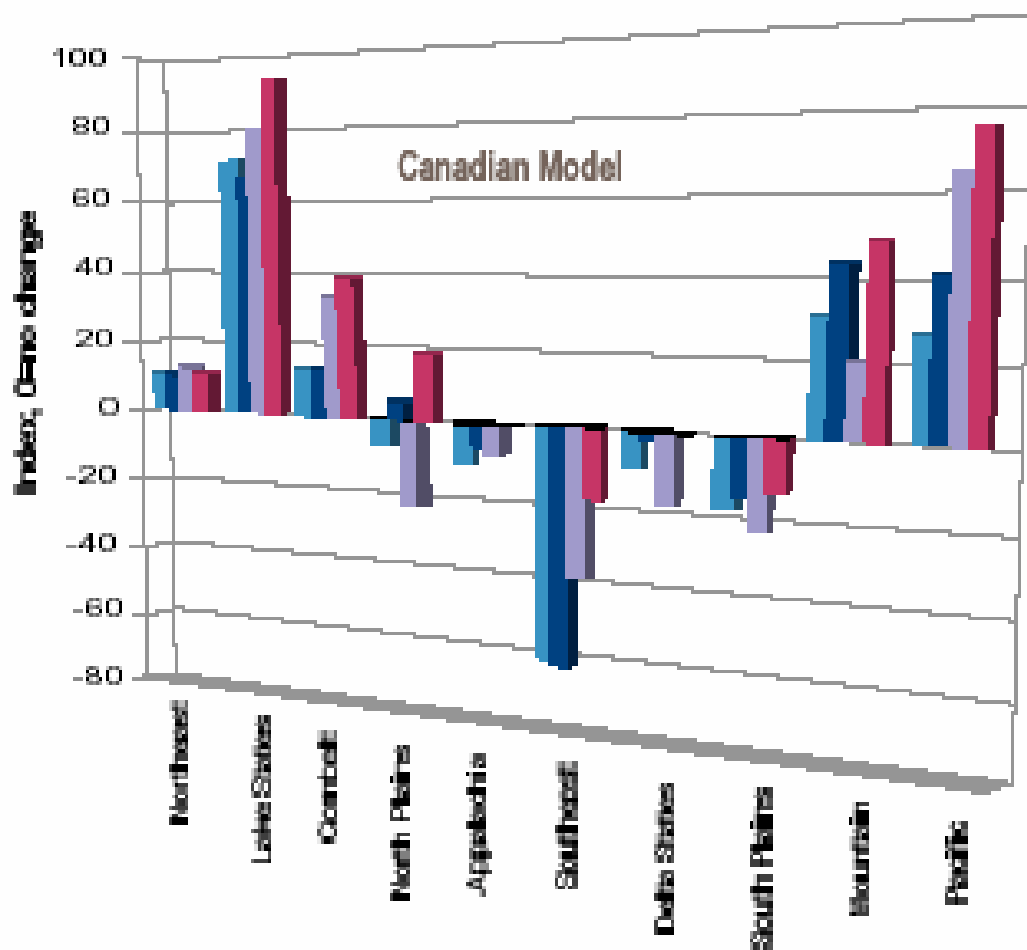


Figure 1a-d. Relative changes (% change relative to present) in crop yield for two time periods, 2030s and 2090s, under the Canadian and Hadley Scenarios. 0 = no change. Under the two climate scenarios, most crops showed substantial yield increase, even without adaptation, under dryland conditions. Irrigated yields increased less or decreased. Source: Changing Climate and Changing Agriculture: Report of the Agricultural Sector Assessment Team, 2000.

Regional Production Changes Relative to Current Production



2030 2030 w/adaptation 2090 2090 w/adaptation

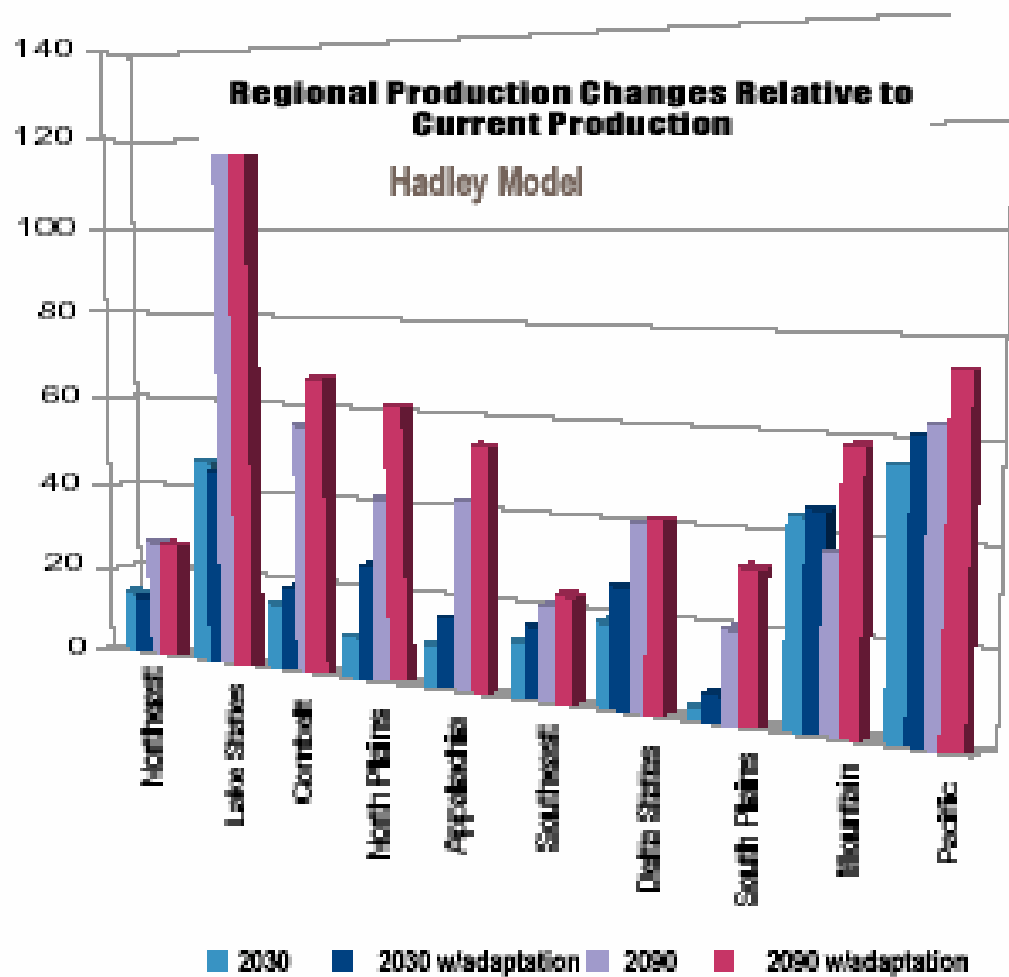


Figure 5a and b. In the model simulations, production increased in northern regions as a result of longer growing seasons, and in western regions due to increased precipitation. Higher temperatures and increased drought conditions contributed to production declines or smaller increases in southern and plains regions. Source: Changing Climate and Changing Agriculture: Report of the Agricultural Sector Assessment Team, 2000.

Assessment Summary

- **At the national level, crops showing generally positive results include cotton, corn, soybeans, sorghum, barley, sugar beets, citrus fruits and pastures.**
- **For wheat, rice, oats, hay, sugar cane, potatoes, and tomatoes, yield results are mixed with increases under some conditions and declines under others.**
- **Regionally, the Midwest, West, and Pacific Northwest show large gains in yields in both time frames and for both models.**
- **Yield reductions were quite large in the South and Plains States for both climate scenarios with declines in precipitation and substantial warming projected in these regions.**

Adaptation Options for Agriculture

- **Change timing of planting, harvesting etc.**
- **Use minimum tillage to improve nutrient and water retention in soils and to reduce soil erosion.**
- **Alter stocking rates on rangelands.**
- **Switch to crops that are less water-demanding and more tolerant of heat, drought, and pests.**
- **Conduct research on new crop cultivars.**
- **Promote agroforestry in dryland areas, including the use of shrubs and trees for fodder.**
- **Replant with mix of tree species to increase diversity and flexibility, and promote reforestation and revegetation initiatives.**
- **Assist natural migration of tree species.**
- **Source: Climate Change 2001, Synthesis Report, Table 3.6, WGII TAR, Cambridge University Press, 2001.**

Adaptation Strategies

- **Sowing dates and other seasonal changes:**
- **Plant two crops instead of one with a short fallow period to avoid excessive heat and drought in mid-summer. For warm growing areas, winter cropping could possibly become more productive than summer cropping.**

Adaptation Strategies

- **Water supply, irrigation, and drainage systems:**
- **Technologies and management methods exist to increase irrigation efficiency and reduce problems of soil degradation, but may need economic incentives.**
Increased precipitation (amount and intensity) will require better drainage systems to avoid flooding and water-logged soils.

Adaptation Strategies

- **Tillage practices:**
- **A warmer climate will speed decay of soil organic matter by bacteria and fungi. Loss of organic matter reduces the capacity of soils to store water and nutrients essential for plant growth. Tillage practices that incorporate crop residues in the soils would likely combat this loss and improve soil quality.**

Adaptation Strategies

- **Use near-term climate predictions:**
- **Accurate six-month to one-year forecasts could possibly reduce losses due to weather variability. Predictions of El Nino events may be useful in regions where El Nino strongly affects the weather.**