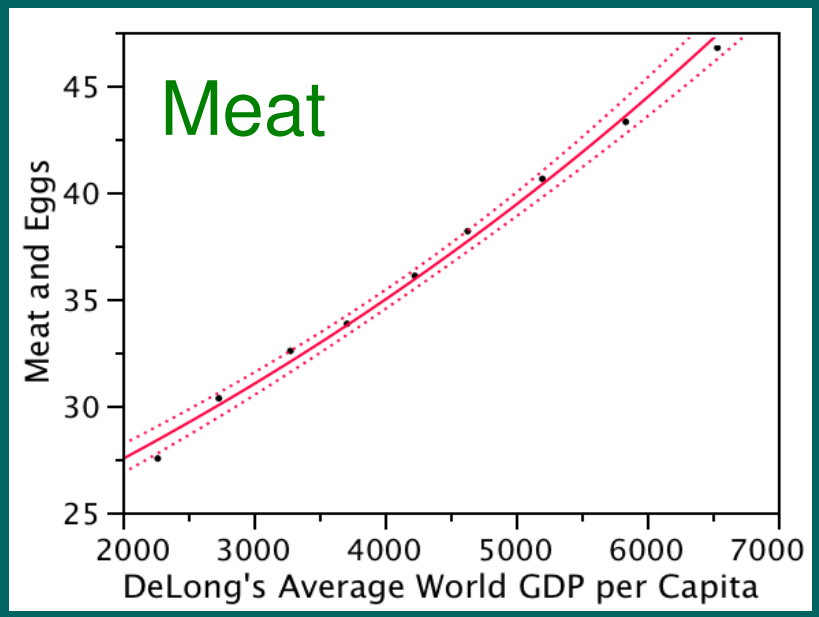
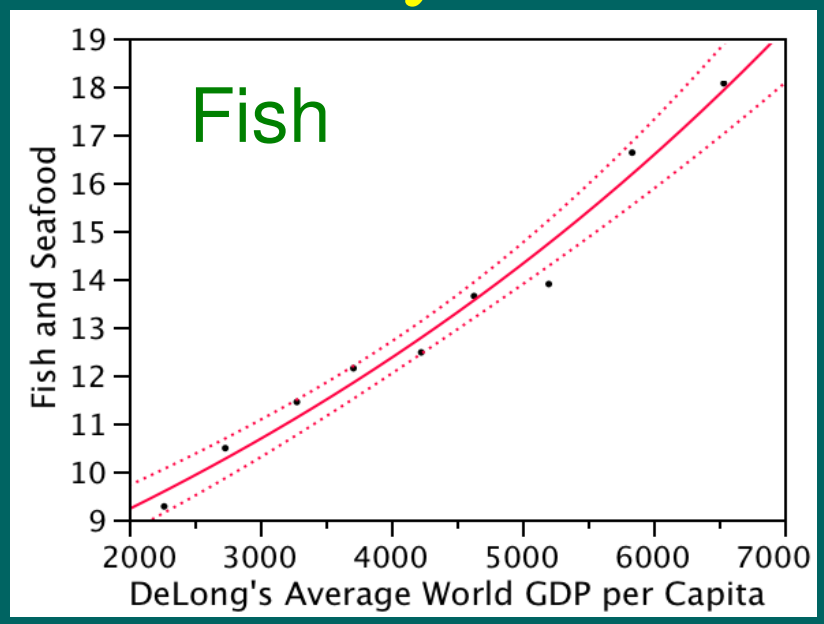
Food, Energy and the Environment: The Next 50 Years

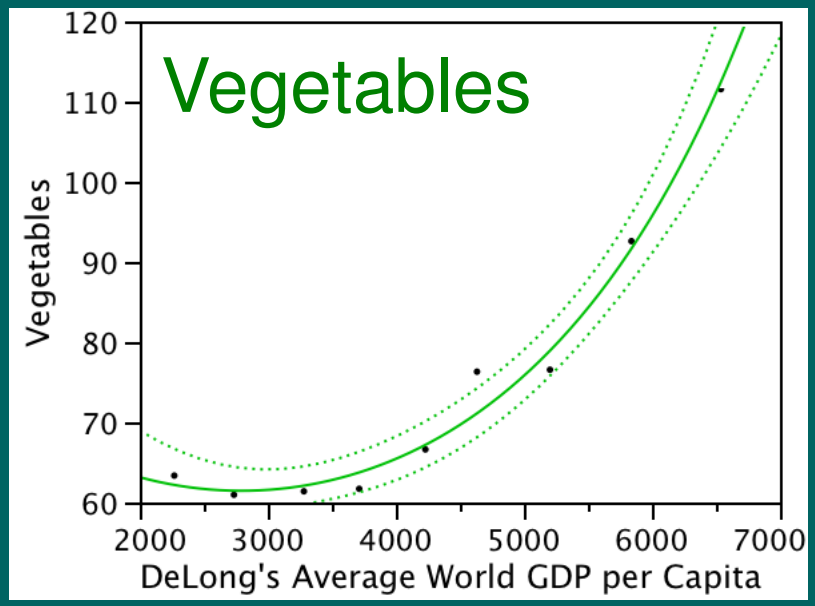
- Global population is projected to increase 50% -- from 6.5 to ~10 billion
- Global per capita GDP is projected to increase 140%. The impacts of increased per capita consumption will be much larger than of increased population
- How might population and consumption drive agricultural demand and its effects on the environment?
- What are the solutions to these problems?

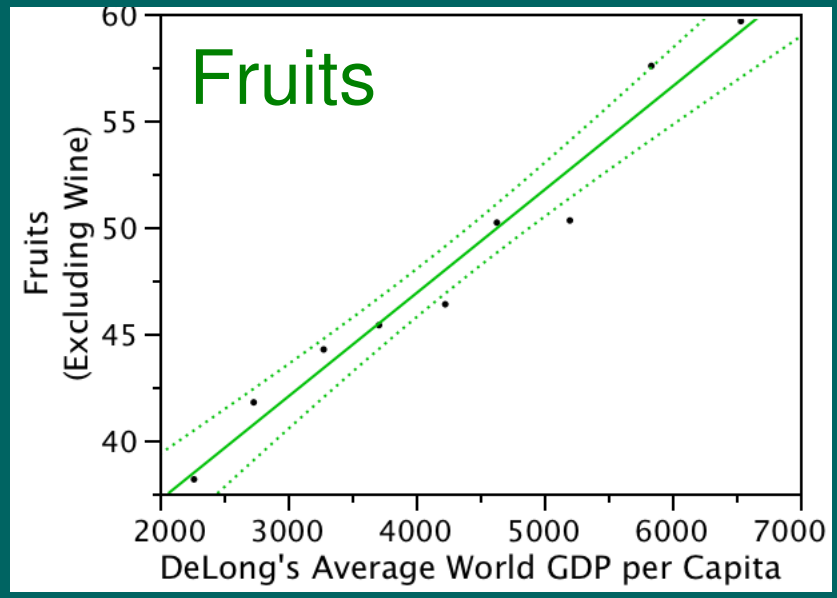
Income and Global Dietary Shifts

Consumption

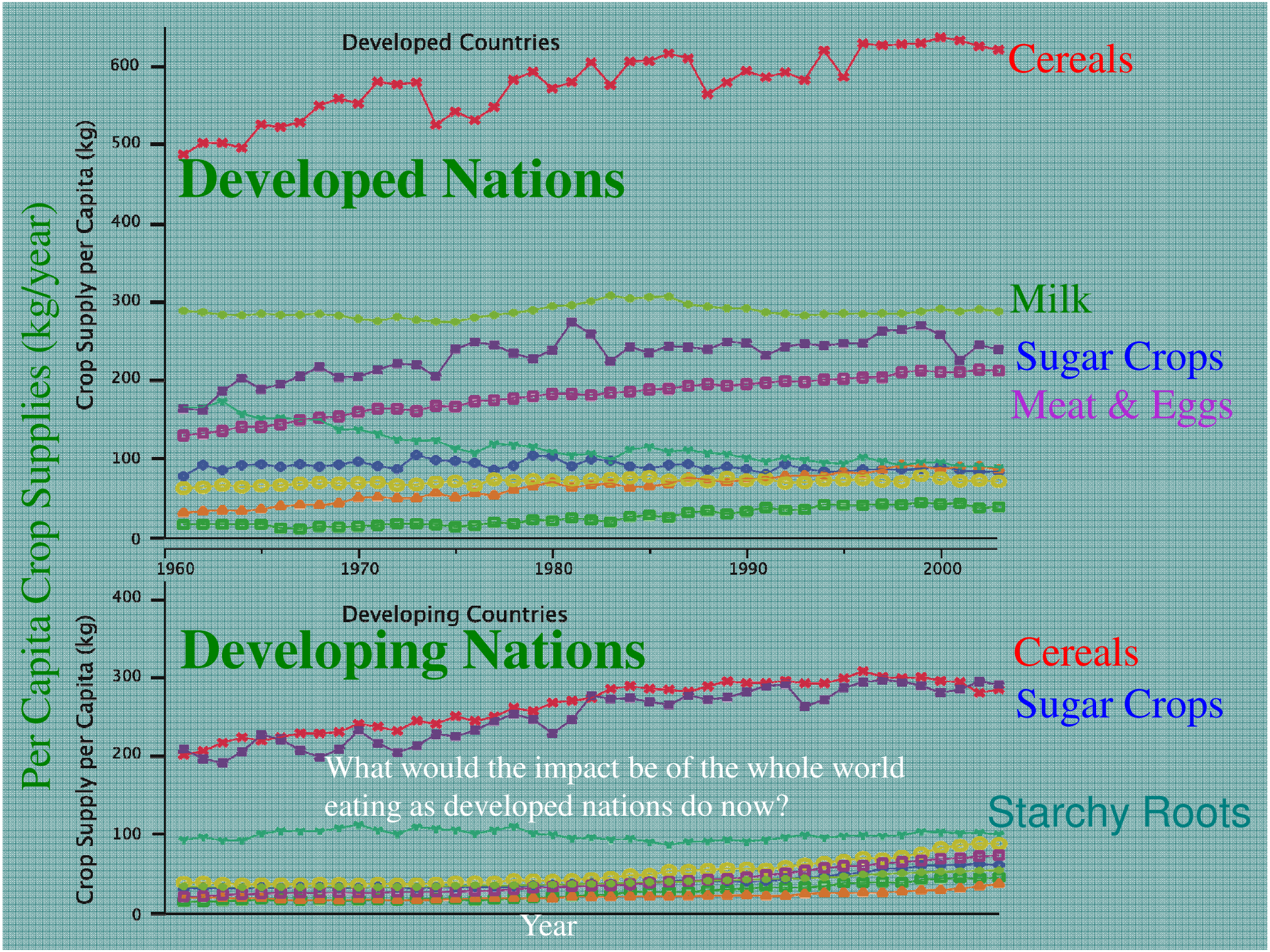








Income


Per Capita Crop Supplies (kg/year)
Developed Countries
Developed Nations
Crop Supply per Capita (kg)
600
500
400
300
200
100
0
1960
1970
1980
1990
2000
Cereals
Milk
Sugar Crops
Meat & Eggs
Developing Countries
Developing Nations
Crop Supply per Capita (kg)
400
300
200
100
0
Cereals
Sugar Crops
Starchy Roots
What would the impact be of the whole world
eating as developed nations do now?
Year

Future Global Food Demand?

- Based on projected global increases in population and per capita incomes, and on observed dietary shifts with income, total global food demand increase 120% in 50 years
- Global food demand would increase 170% if all nations attained the diets of developed nations

Increase Yield or Land?

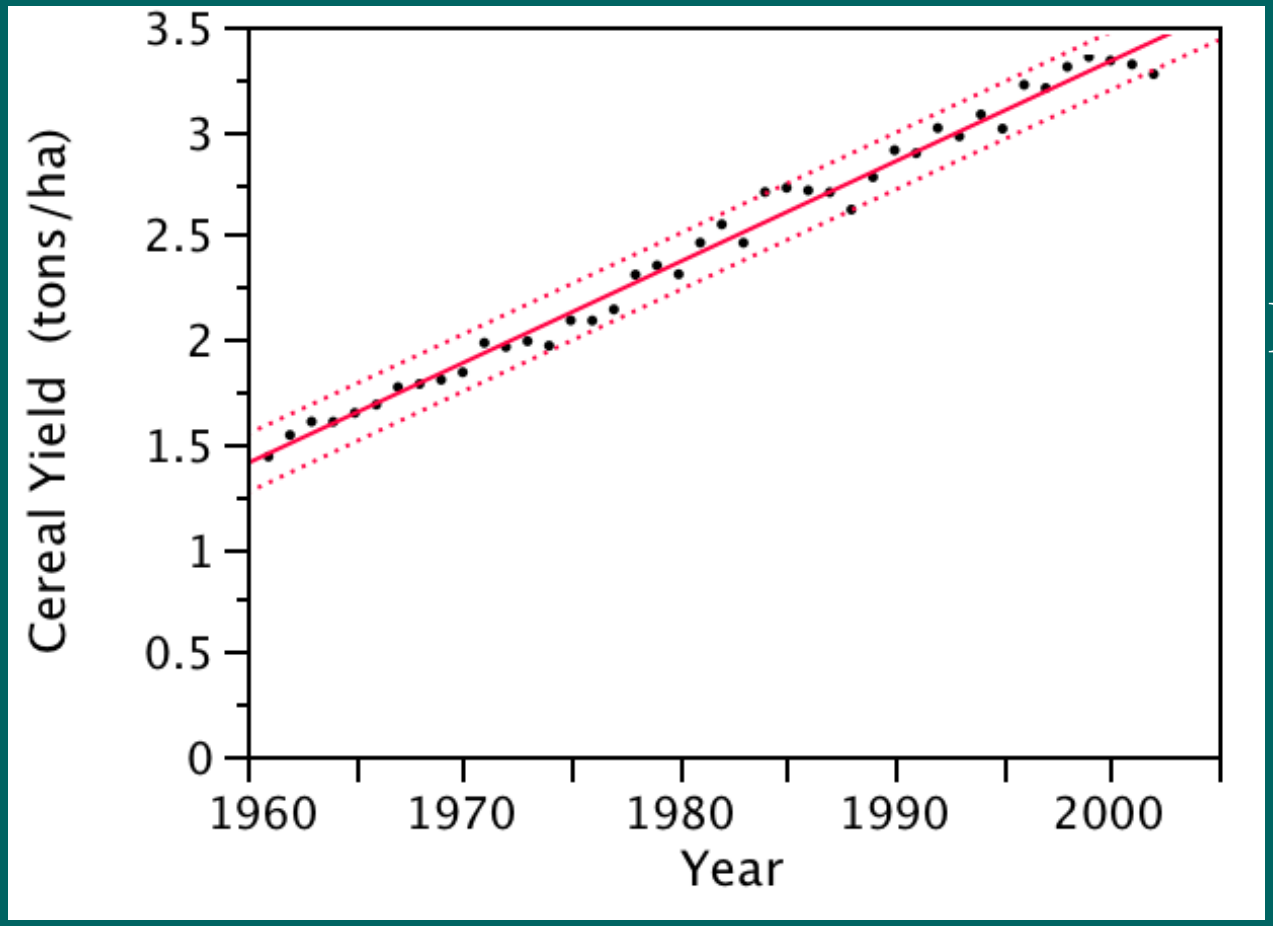
Environmental Impacts of Global Food Production at 120% to 170% More Than Current Levels

Production =

Yield • Land Area

[tons/hectare • hectares]

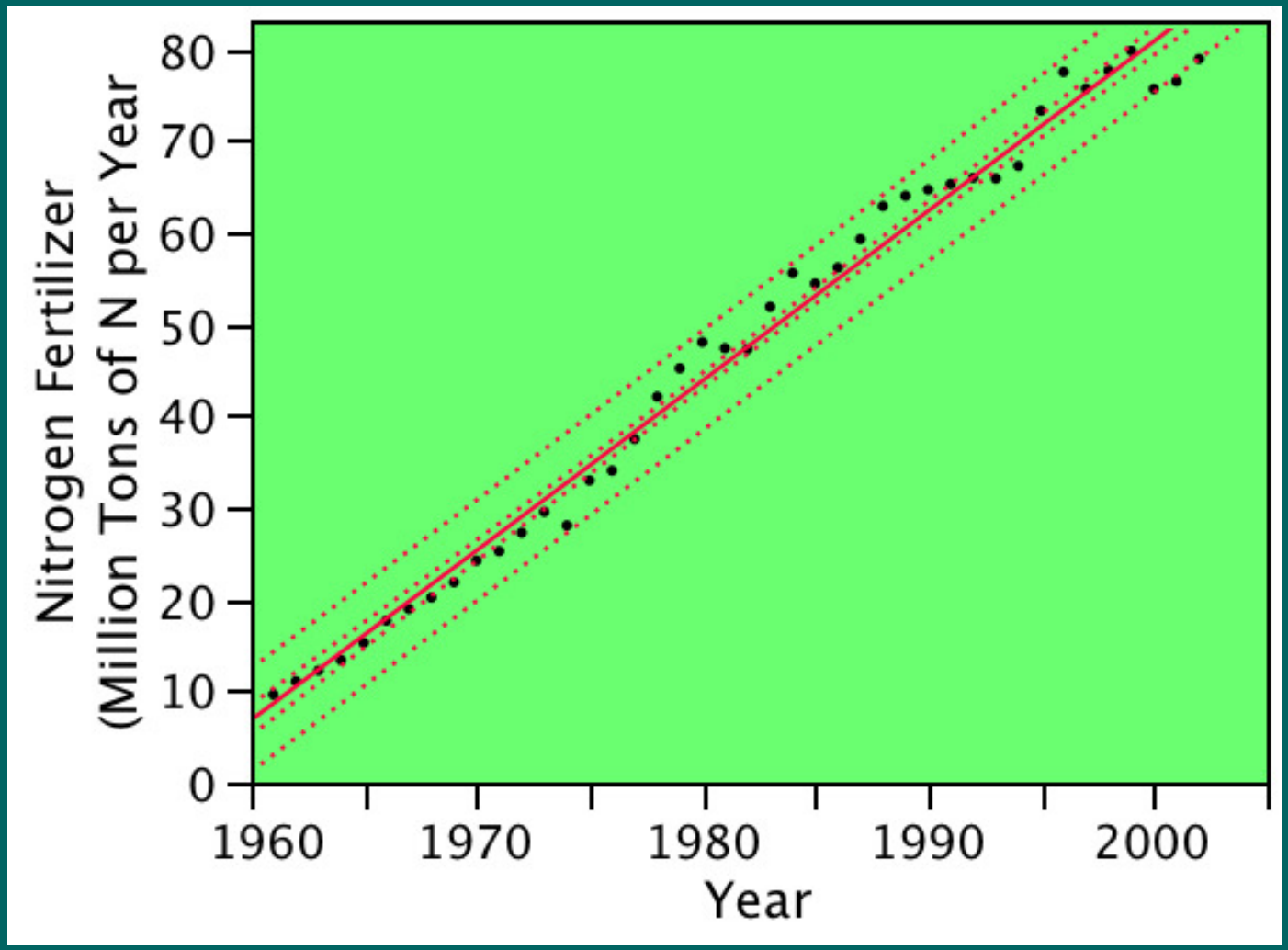
Global Cereal Yield Trends



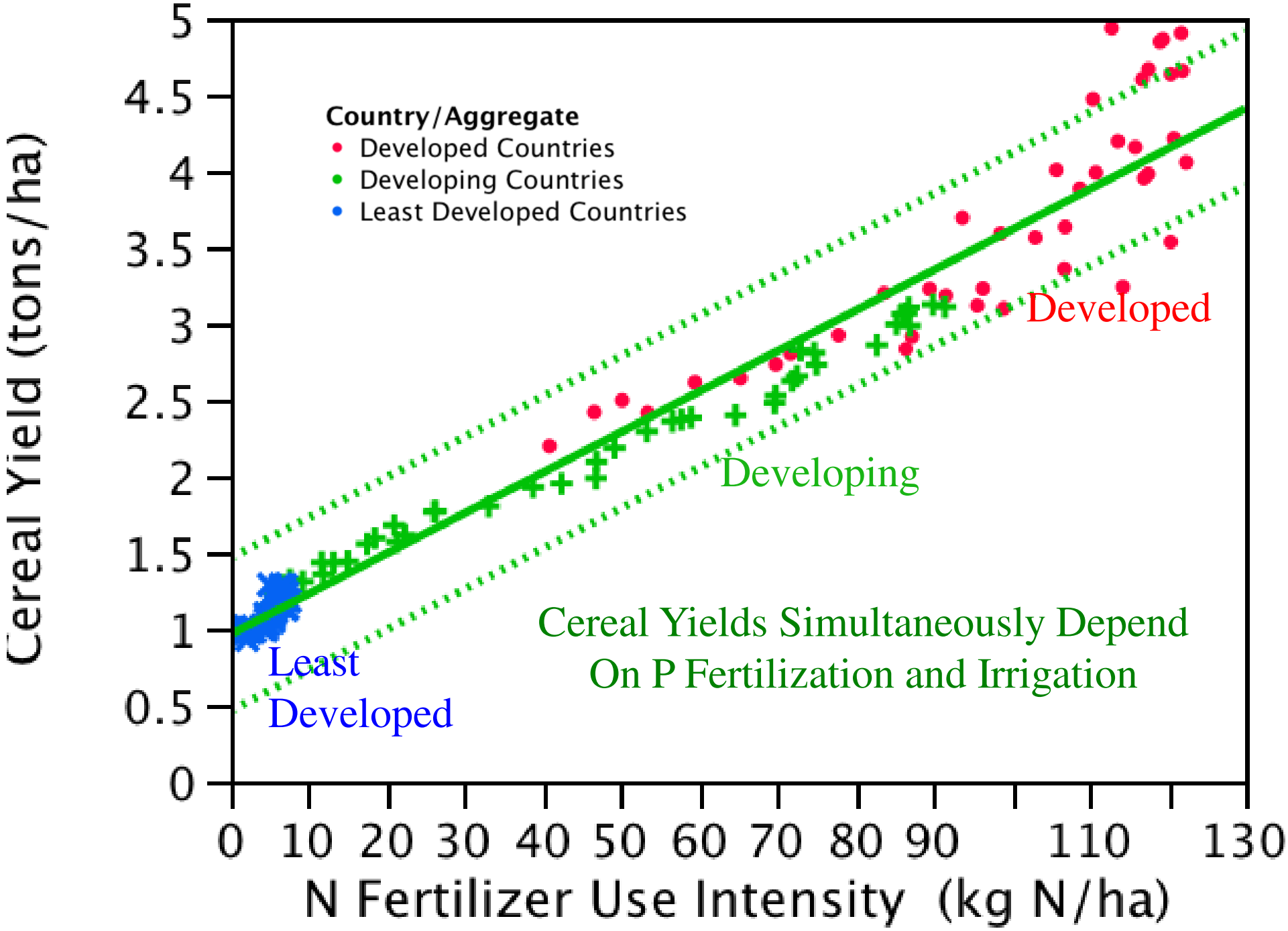
If This Rate Of Yield Gain Could Be Maintained For 50 More Years, Global Cereal Yields Would Increase By 70%

For a Weighted Mix of All Major Crops Combined, Global Yields Are on Trajectory to Increase 66% in 50 Years

Doubling Global Food Production Required 7-Times the Nitrogen Fertilization and



3-Times the Phosphorus Fertilization & 40% More Irrigation


Country/Aggregate
Developed Countries
Developing Countries
Least Developed Countries
Developed
Developing
Least Developed
Cereal Yields Simultaneously Depend On P Fertilization and Irrigation
Cereal Yield (tons/ha)
N Fertilizer Use Intensity (kg N/ha)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
110
130

Environmental Impacts of N, P, Water, Herbicides & Other Pesticides

- Nitrogen, Phosphorus and Water are the Three Major Factors Limiting and Structuring the Earth's Terrestrial and Aquatic Ecosystems
- The 5 Million Species of Earth are Adapted to Low Levels of these Limiting Resources
- Elevated Levels Disturb Natural Ecosystems, Harm their Functioning, and Cause Loss of Biological Species Diversity
- Pesticides can be endocrine distrupters or carcinogens

Native Prairie Receiving No Added Nitrogen Deposition

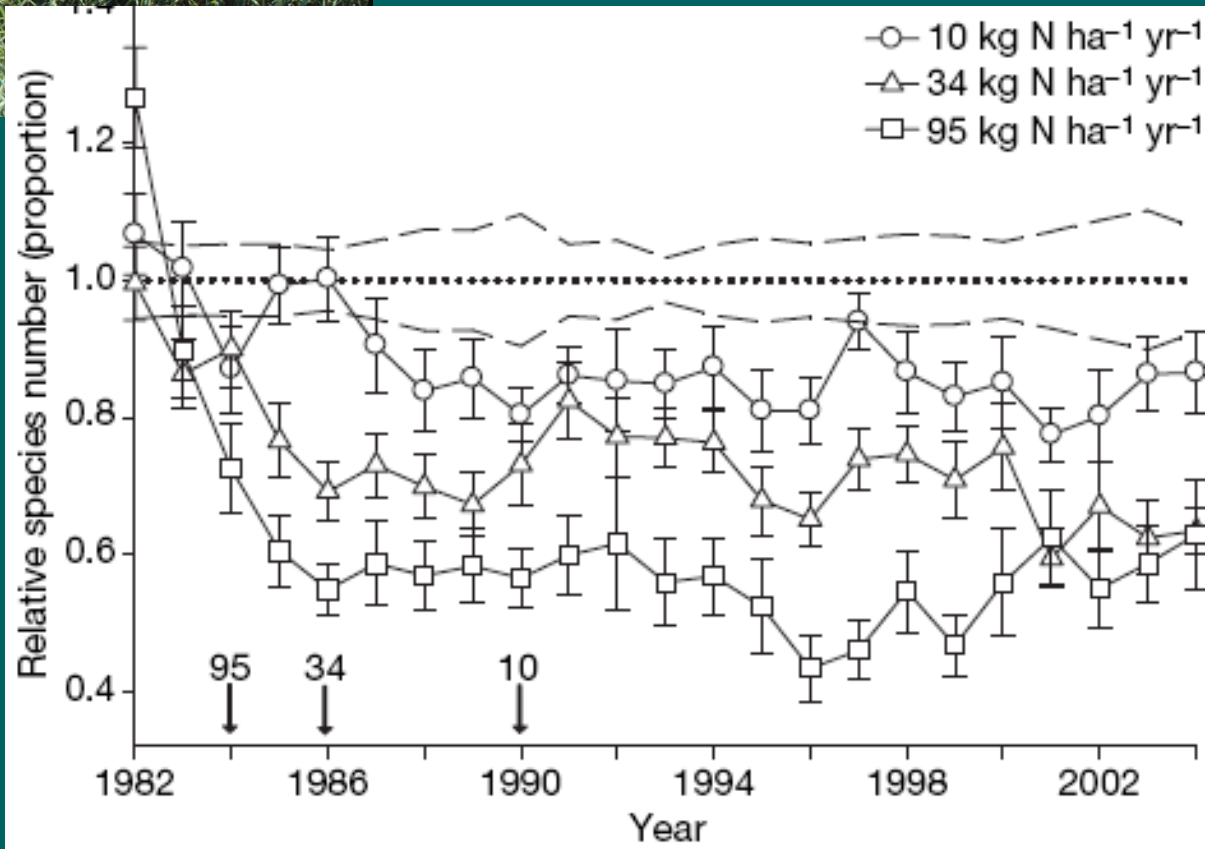
A Control Plot in a 207-Plot Nitrogen Addition Experiment

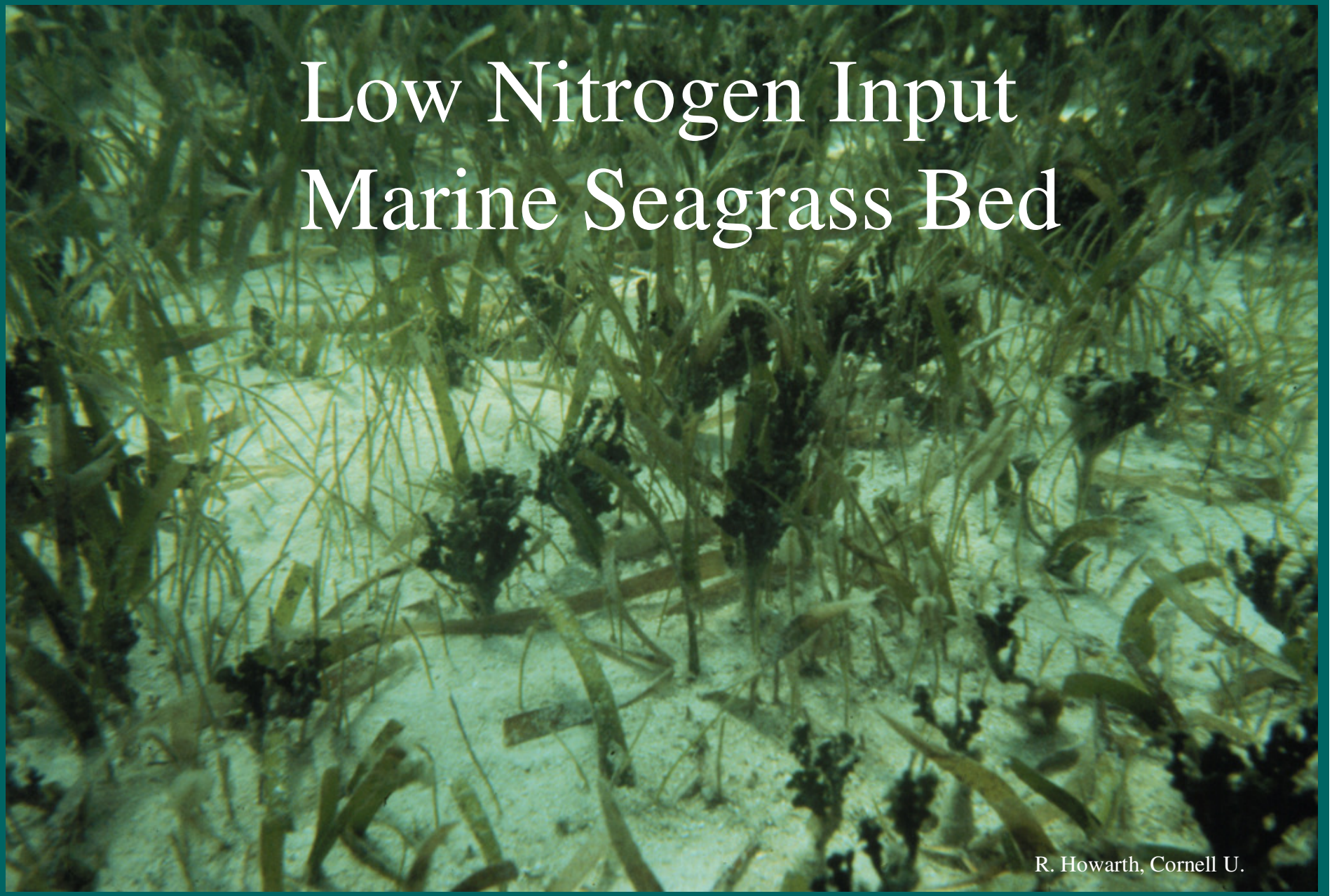
Chronic Nitrogen Deposition Causes Loss of Biodiversity

Rate of Atmospheric Deposition of Agriculturally-Derived Nitrogen Would Increase 200%

Chronic Addition of 34 Kg/ha of N Caused Local Loss of 30% of Plant Species

(Clark & Tilman 2008 *Nature)*




Low Nitrogen Input
Marine Seagrass Bed
R. Howarth, Cornell U.

High Inputs: Loading of Agricultural Nitrogen to Marine Ecosystems Causes "Dead Zones"

R. Howarth, Cornell U.

Inputs Needed if Yields Double Again?

Forecasts for Global Nitrogen Fertilization

(Currently 88 x 10^6 MT yr^{-1} of N)

Forecast Method	Value for Year 2050	Factor
Double Global Food	276	3.1
Population - dependence	154	1.8
GDP - dependence	349	4.0
Temporal Trend	188	2.1
Population + GDP + Year	371	4.2
Mean Forecast	**277**	**3.04**

(Tilman et al. 2001 Science)

Forecasts for Global Use in 2050:

Nitrogen Fertilizer	204% increase
Phosphorus Fertilizer	150% increase
Irrigated Land	90% increase
Pesticide Use	160% increase

Environmental Impacts

- Large Increases In Number And Sizes Of Marine "Dead Zones" From Agricultural Nitrogen Loading to Rivers

- Nitrogen And Phosphorus Pollution (Eutrophication) Of Lakes, Rivers And Streams Increases – Threatening Freshwater Fisheries

- Decreased Ground Water Quality For Human Use From Increased Leaching Of Nitrate, Nitrite And Agricultural Herbicides And Pesticides

- More Dry Rivers And Over-Exploited Aquifers From Doubling Land in Irrigation

Food Production at 2.2 to 2.7 Times Current Levels

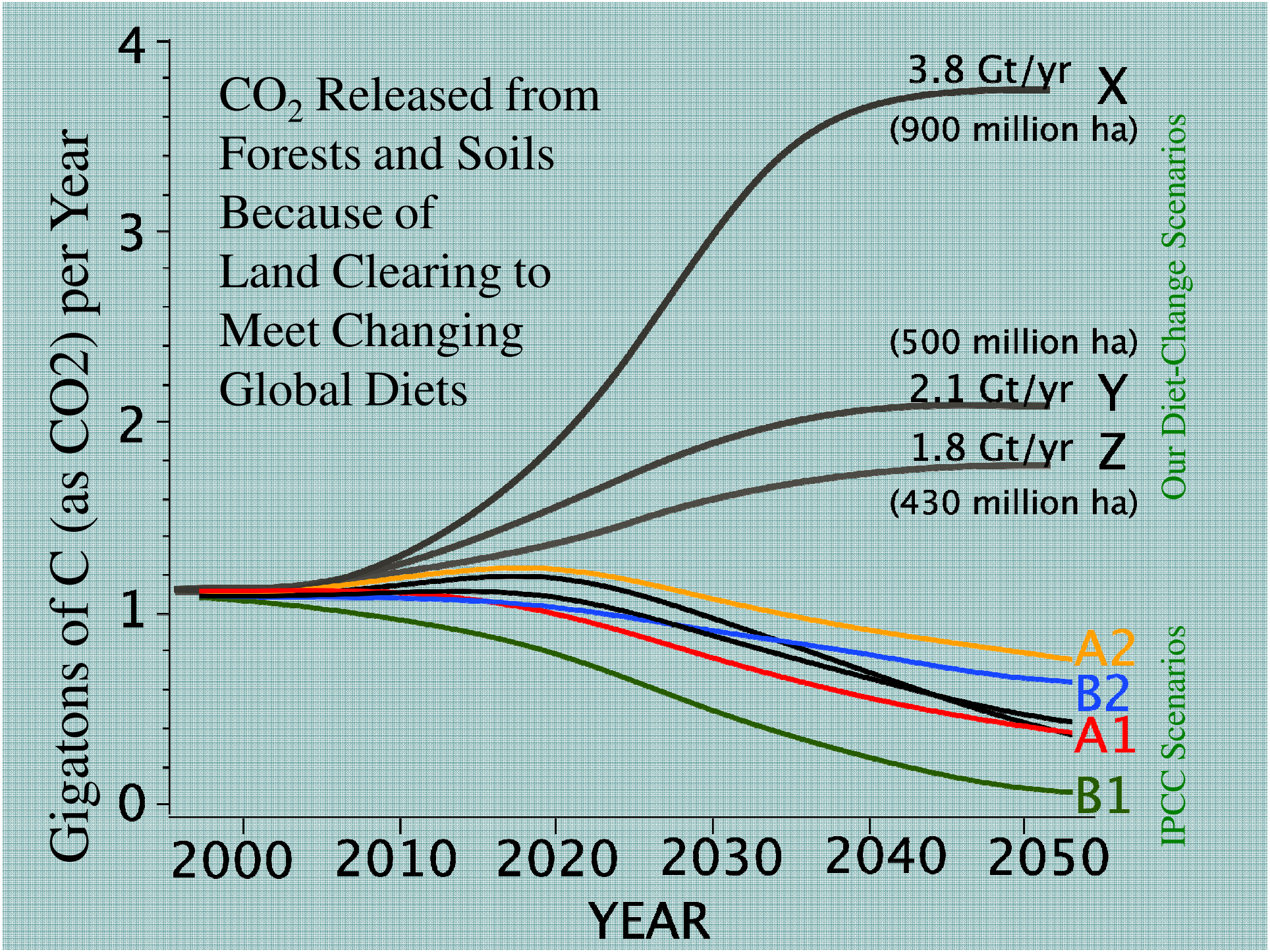
Also Would Require from 35% to 65% More Crop Land

(~500 to 950 million hectares)

About 540 Million Hectares of Pasture Land Would Also Be Needed for Meat/Dairy Production

Most New Land from Clearing Tropical Forest & Savanna

1. Loss of biological diversity from destruction of about 1/3 of remaining tropical forests and savannas
2. Large releases of greenhouse gasses (CO_2) from trees and soils
3. Loss of other ecosystem services

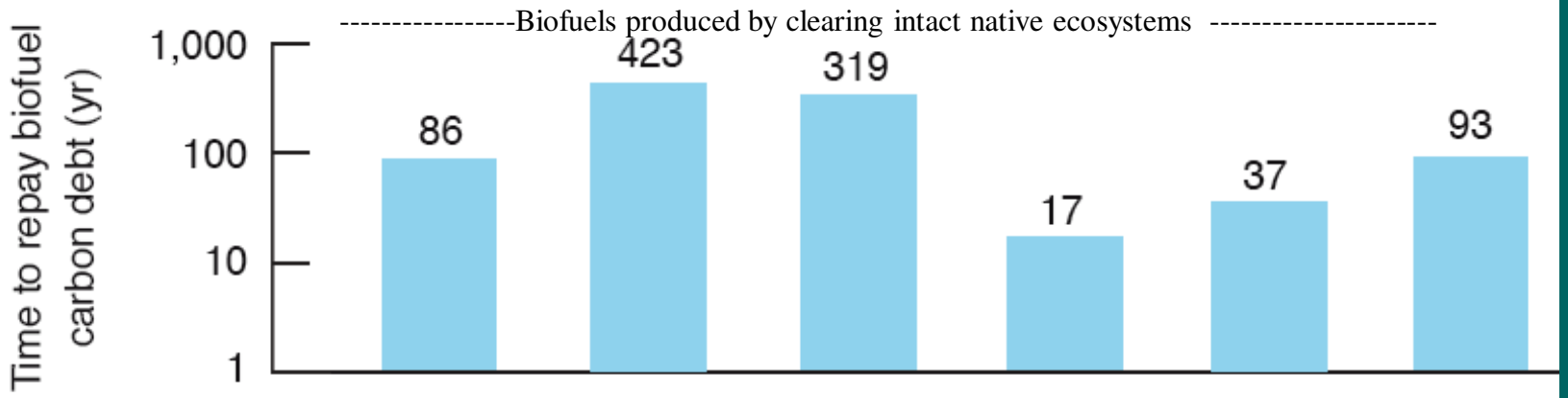

CO_2 Released from Forests and Soils Because of Land Clearing to Meet Changing Global Diets
Gigatons of C (as CO2) per Year
4
3
2
1
0
2000
2010
2020
2030
2040
2050
YEAR
3.8 Gt/yr
X
(900 million ha)
(500 million ha)
2.1 Gt/yr
Y
1.8 Gt/yr
Z
(430 million ha)
Our Diet-Change Scenarios
A2
B2
A1
B1
IPCC Scenarios

Meat and Dairy Greenhouse Gas Loading in 2050

- If world had per capita meat and dairy consumption of developed nations, methane and nitrous oxide from livestock would be equivalent to 5.4 gigatons/year of C (as CO_2).
- If current diet and yield trends continue, release would be about 3 gigatons/year
- If current trends continue, land clearing and livestock combined would contribute almost as much GHG as current fossil fuel combustion

Food-Based Biofuels?

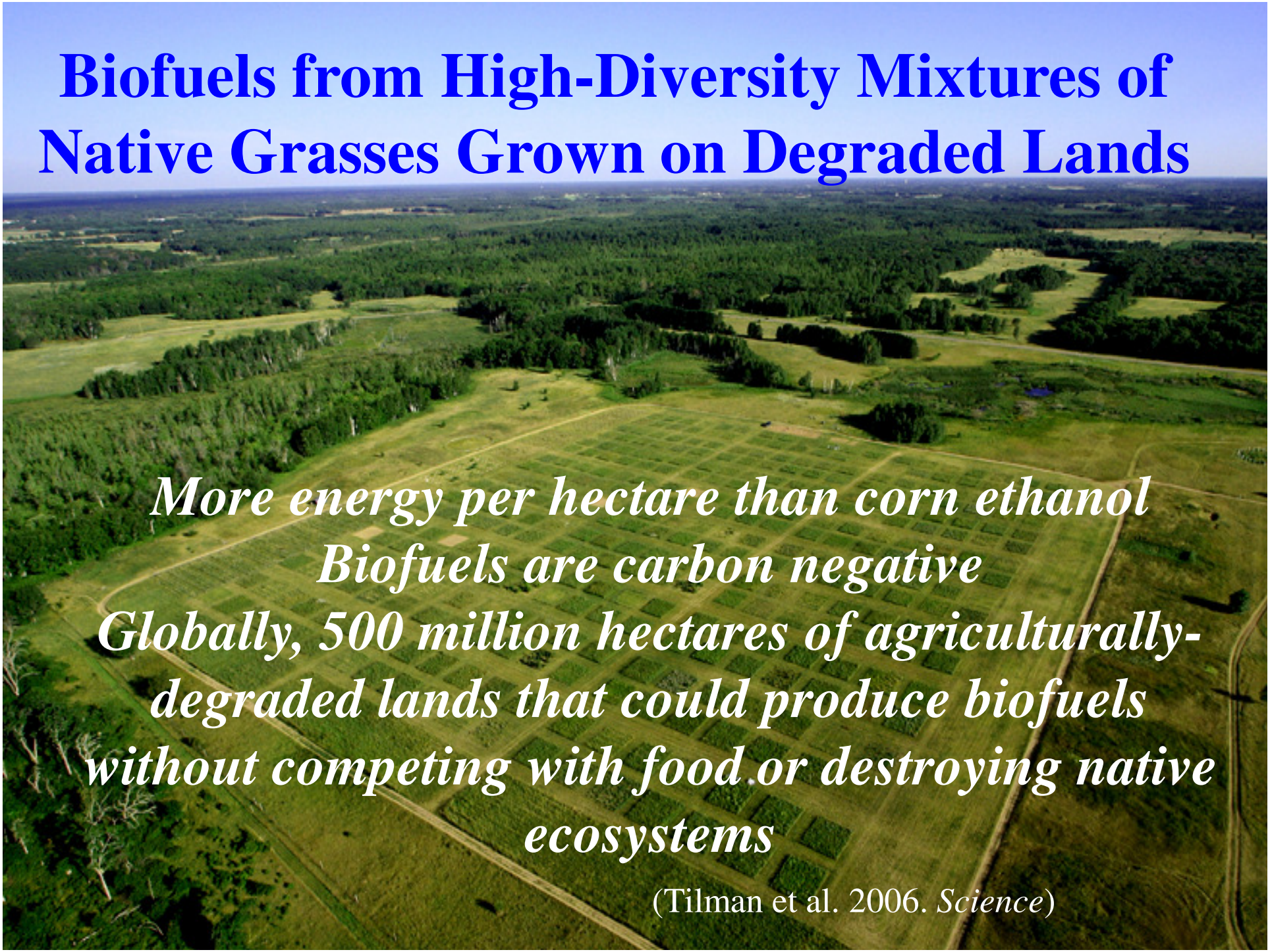
Food-Based Biofuels Require New Land Or Take Land From Food Crops



Biofuel	Palm biodiesel	Palm biodiesel	Soybean biodiesel	Sugarcane ethanol	Soybean biodiesel	Corn ethanol
Former ecosystem	Tropical rainforest	Peatland rainforest	Tropical rainforest	Cerrado wooded	Cerrado grassland	Central grassland
Location	Indonesia/ Malaysia	Indonesia/ Malaysia	Brazil	Brazil	Brazil	US

Biofuels can be worse for climate change than gasoline or diesel (Fargione, Hill & Tilman 2008 *Science*)

Biofuels from High-Diversity Mixtures of Native Grasses Grown on Degraded Lands



More energy per hectare than corn ethanol
Biofuels are carbon negative
Globally, 500 million hectares of agriculturally-degraded lands that could produce biofuels without competing with food or destroying native ecosystems

(Tilman et al. 2006. *Science*)

Three Solutions to the Food - Environment Dilemma

1. Invest in Higher Gains in Crop Yields

1. Major investment in crop breeding for cereals and non-cereal crops and meat

2. Governmental investment in crops not profitable for seed companies

3. Infrastructure, seeds and technologies for farmers of least developed nations, especially in Africa where yields are 1/4 those of other similar regions

If Future Gains in Yield Are Increased to Match Those of the First 20 Years of the Green Revolution,

Future Land Clearing Could Be Reduced by about 40%

2. Eat Higher-Efficiency Animal Protein and/or Less Animal Protein

Animal Species	Dry Grain : Usable Meat
Cattle (CAFO)	14 kg/kg
Pigs	7 kg/kg
Poultry	3.5 kg/kg
Fish aquaculture	1.5 kg/kg

Shifts in types or amounts of meat consumed can cause large shifts in cereal demand and the land and agrichemicals needed to produce it.

Agricultural Land Clearing Changes by Shifting Our Diets

1. Same per capita animal protein as developed nations but with 80% less beef+pork:

   49% less new land needed

2. 20% less per capita animal protein with 80% less beef+pork:

   69% less new land needed

3. ***Invest in increasing crop yield to that of the early Green Revolution*** and ***diet shifts*** to 20% less per capita animal protein with 80% less beef+pork:

   91% less new land needed

3. High Efficiency Agriculture

1. Seek yield gains that do not require increased inputs
2. Apply lowest effective amounts of N, P, water and pesticides at correct times
3. Grow crops that optimize nutrition per unit input and per hectare
4. Reward farmers for all the goods and services they provide (clean water, storage of carbon in soil, increased soil fertility, etc.) not just tons of crop produced

Guidelines for a Sustainable Globe

For Food:

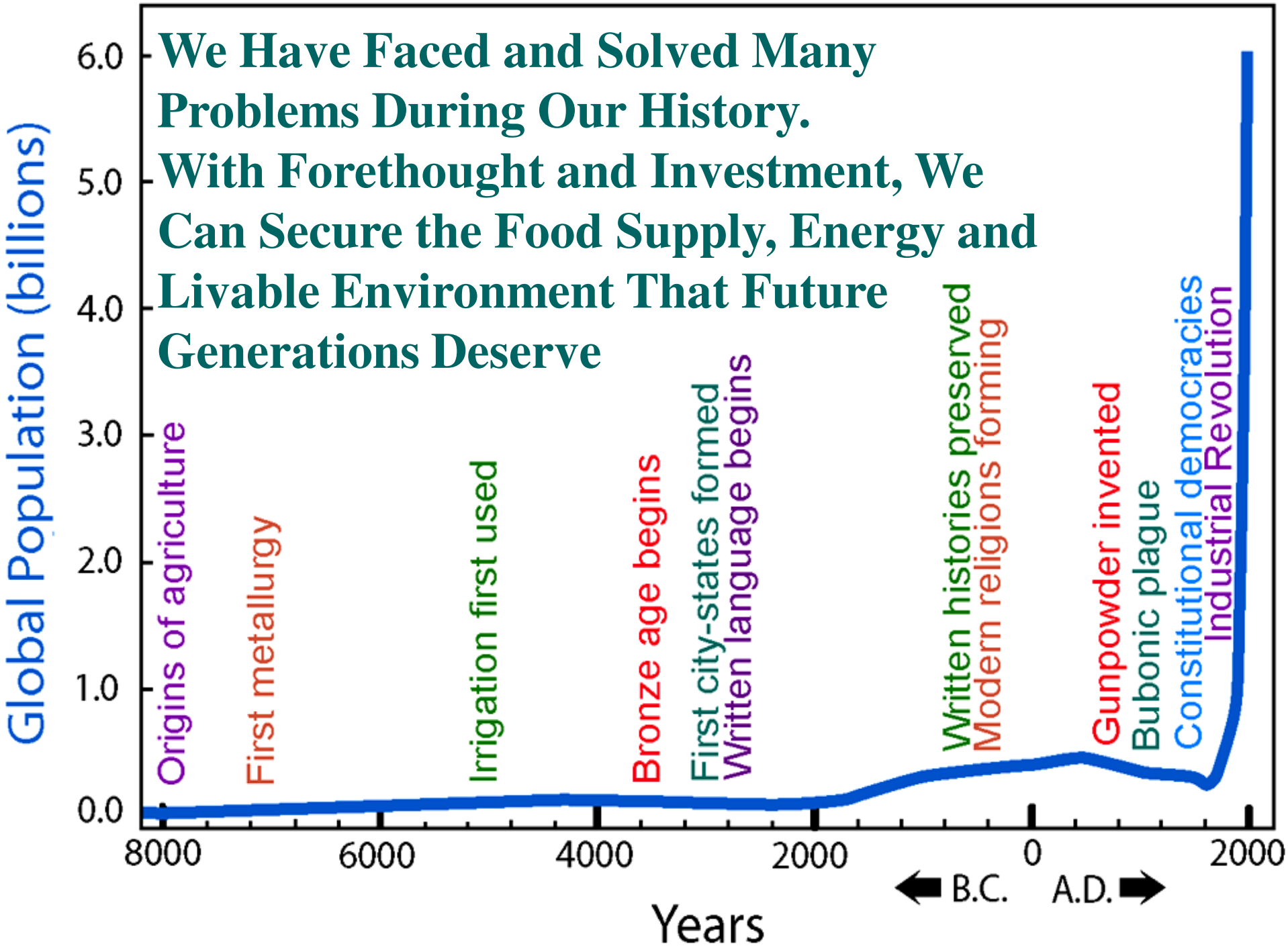
•Invest in yield gains of major crops and in nutrient efficiency

•Create meals featuring more efficient meats, or less meat, that are highly appealing

For Biofuels:

•Use wastes and degraded land - not fertile land - for biofuel production

•Use biodiversity as a tool to optimize energy gains and carbon sequestration


We Have Faced and Solved Many Problems During Our History.
With Forethought and Investment, We Can Secure the Food Supply, Energy and Livable Environment That Future Generations Deserve
Global Population (billions)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Origins of agriculture
First metallurgy
Irrigation first used
Bronze age begins
First city-states formed
Written language begins
Written histories preserved
Modern religions forming
Gunpowder invented
Bubonic plague
Constitutional democracies
Industrial Revolution
8000
6000
4000
2000
0
2000
B.C.
A.D.
Years