Macdonald Campus of McGill University

Faculty of Agricultural & Environmental Sciences

Agricultural Research in the 21st Century

International Trends and Developments

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Structure

- Food
- Energy
- Climate change
- Environment
- Solutions

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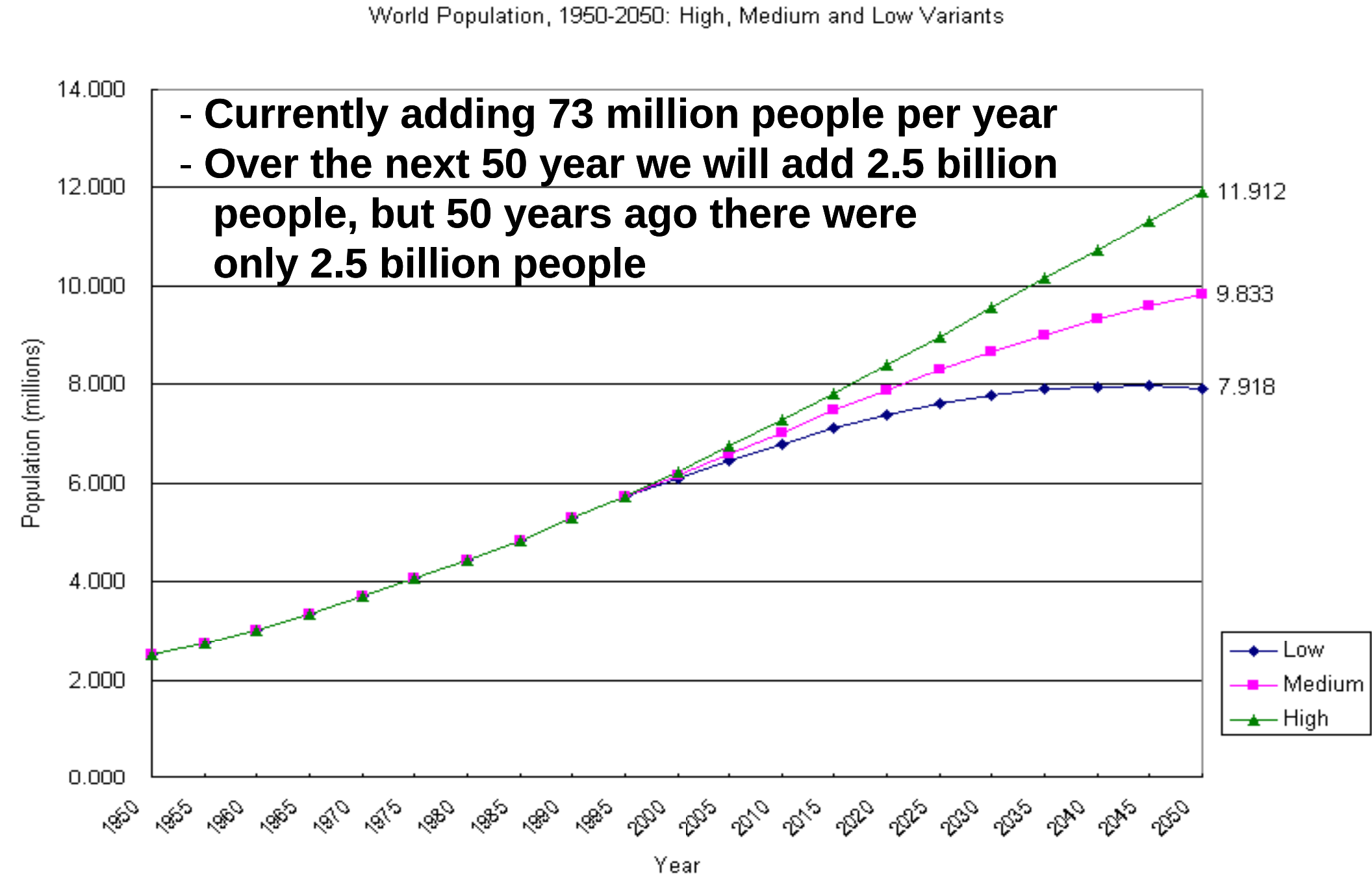
World Population

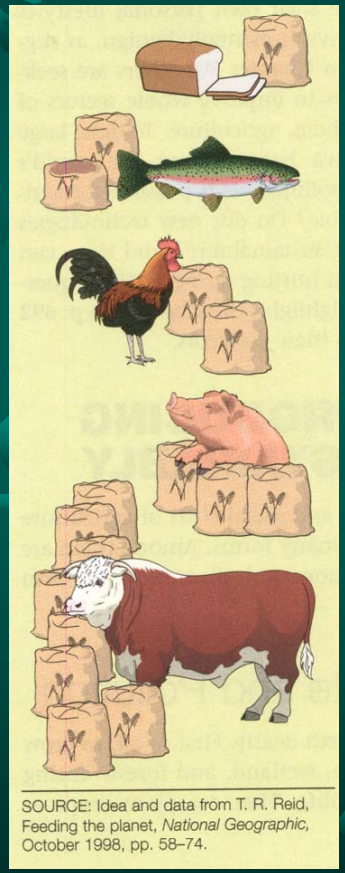

World Population, 1950-2050: High, Medium and Low Variants
- Currently adding 73 million people per year
- Over the next 50 year we will add 2.5 billion people, but 50 years ago there were only 2.5 billion people
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
Population (millions)
11.912
9.833
7.918
Low
Medium
High
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year

The Meat Revolution

- Throughout the developing nations, as wealth increases, so does meat consumption
- At the crop level we see this in an increasing demand for maize (a livestock feed crop) and a decrease for rice (direct human consumption)

Converting Grain to Meat

- 2 kg of grain produce 1 kg of poultry
- 4.5 kg of grain produce 1 kg of pork
- 8-10 kg of grain produce 1 kg of beef



SOURCE: Idea and data from T. R. Reid, Feeding the planet, *National Geographic*, October 1998, pp. 58–74.

Recent Progress

- Since 1950 global cereal yields have increased about 2.5-3 fold
- Soybean yield has increased ~2 fold
- In more research intensive areas progress is even larger
  - U.S. corn yields have increased 3.5 fold
  - There has, however, been some decrease in quality

- Without sustained research population would never have reached current levels and the last century would have been a time of chronic famines throughout the world

Research – The Last 100 Years

- Management (~1/2)
  - disease control
  - weed control
  - insect control
  - irrigation
  - fertilizers
- Genetics (~1/2) - plant breeding)
  - pest (disease and insect) resistance
  - stress tolerance
  - improved harvest index
  - higher yields
  - improved quality

Harvest Index

- Proportion of the total plant material that is in the material that we harvest and, for the most part, eat
- During the 20th century these have increased from approximately 30 % to over 50 %
- Is growing concern and evidence that this is coming to an end

Green Revolution - Integration

- Brought together two key factors, one management, one genetic
- Problem:
  - high fertilizer lead to taller plants with more seed on top (heavier) and they fell over
- Solution:
  - dwarfing genes made the plants short and allowed increased fertilizer applications and yield

Where We Can't Go Again

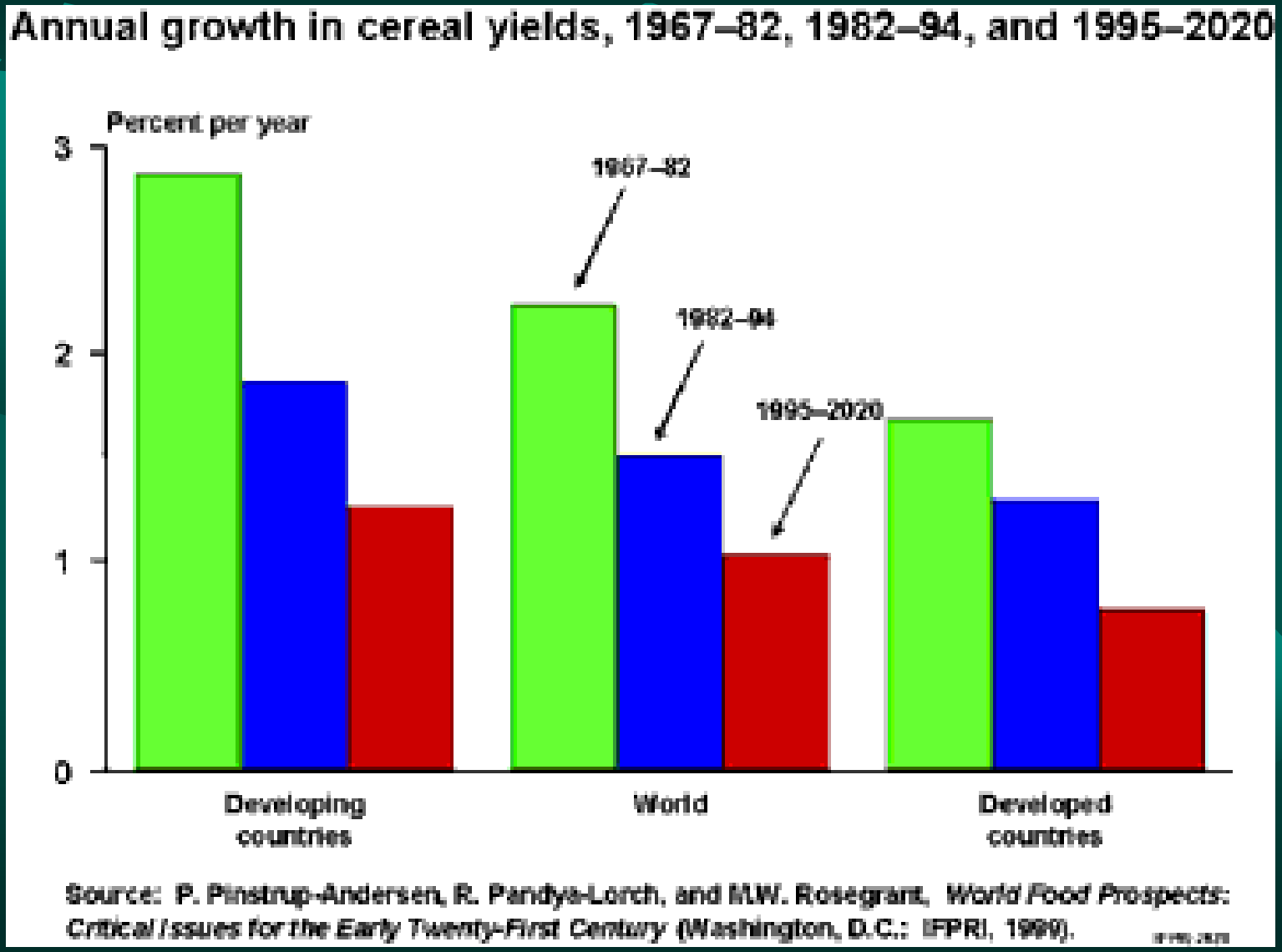
- We are at saturation for N fertilizer additions, we are likely to be legislated back for environmental reasons, and it is energetically expensive
- There is little room for net expansion of irrigated land (salinization and aquifers pumped out)
- Harvest index has been pushed about as far as it can go

granular ammonium nitrate

Other Improvements

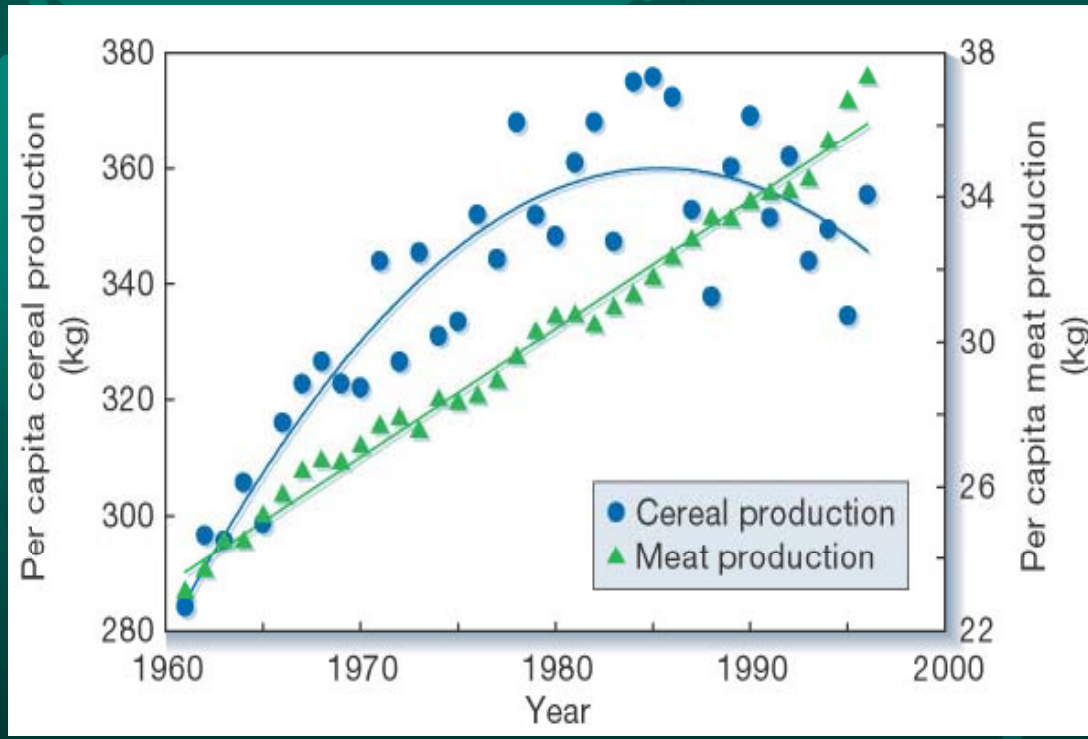
- There were also improvements in other areas:
  - canopy structure
  - narrower rows
  - pest control
  - stress tolerance

Rate of Yield Increase is Declining



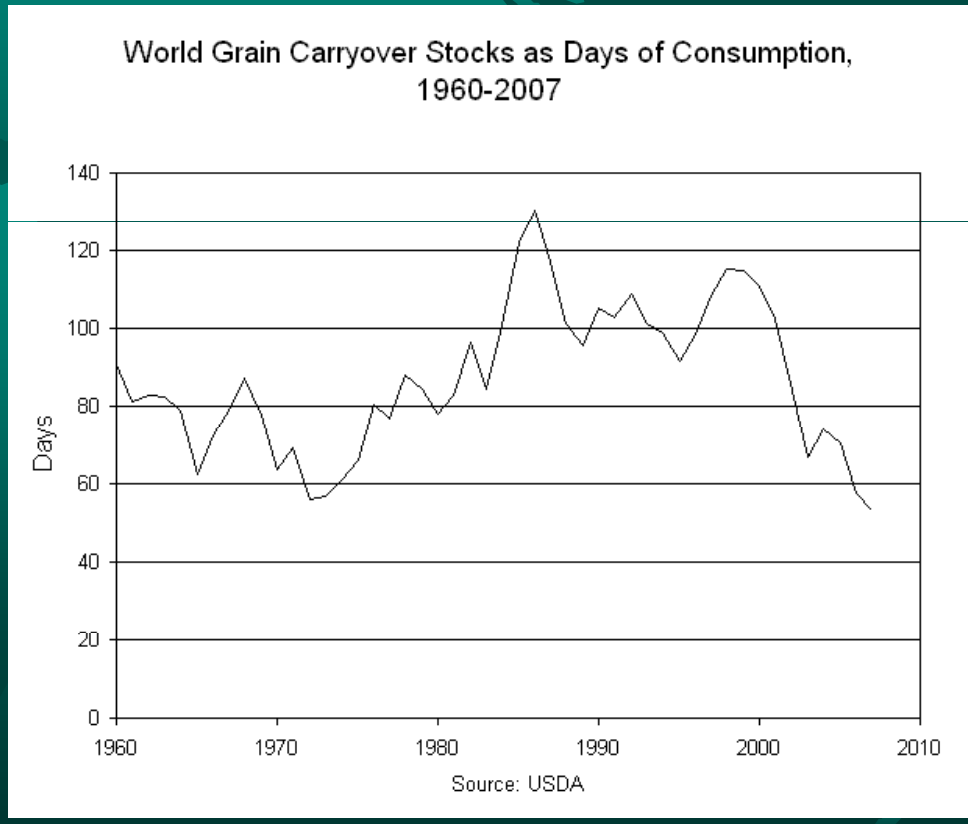
Cereals Per Capita

- While absolute cereal output is still increasing we are slipping when matched against the population increase
- For the first time in fifty years the per capita cereal production is falling



The Larder is Almost Bare

- During the early 80's world grain stores were equivalent to about ½ year of consumption
- In theory, if no grain was harvested in a given year, all could eat
- Current grain supplies are on the order of 40 days
- This has been attracting the interest of speculators
- Flooding in the corn belt leads to a 21 day projection for corn

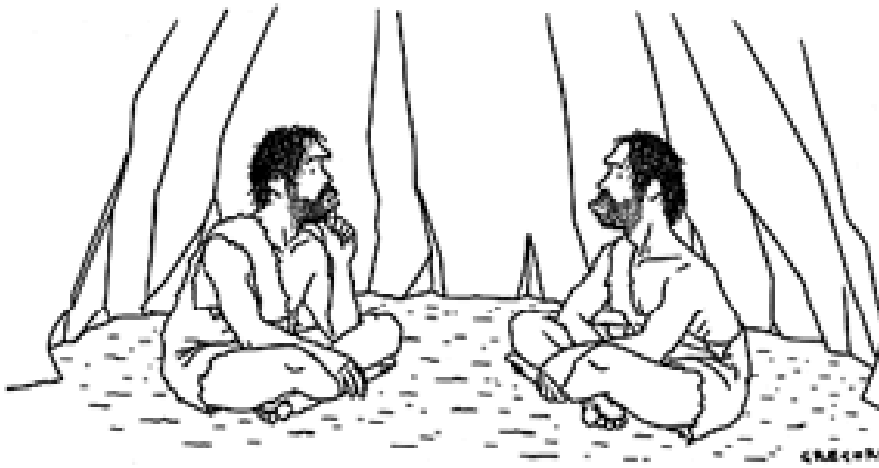


Next Trophic Level

- Milk production has increased 2.5 fold in the last 50 years (60% management, 40% genetics)
- Efficiency of meat production in pork has doubled
- This is important as there is a trend toward increasing meat consumption

Food Safety

- Growing concern about food quality and food borne diseases
- Growth in viral diseases (H5N1)
- Also things like BSE
- Also concerns about pesticides, pollutants and GMOs
- More than half of the Europeans believe that healthy nutrition has a positive effect on staying healthy and prevention of diseases
- At the same time - a desire for convenience



"Something's just not right—our air is clean, our water is pure, we all get plenty of exercise, everything we eat is organic and free-range, and yet nobody lives past thirty."

Consumer Concerns

- Animal welfare
- Ethical foods
- Fair trade
- Organic

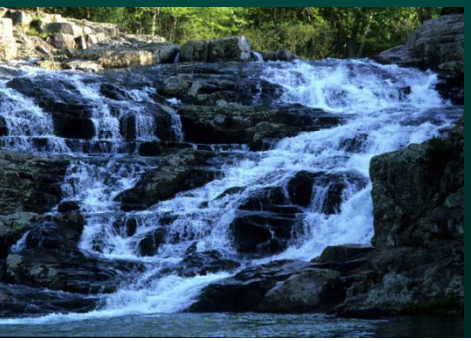
Research & Food Safety

- Nano packaging – edible and biodegradable
- RFIDs – food tracking
- Sensors – detection of disease organisms and toxins
- Functional foods – nutraceuticals and other health related materials
- Probiotics

Viability of Rural Regions

- Becoming depopulated of food producers
  - Fewer, larger farms
  - Fewer younger people

- Increasingly invaded by exoburbanites
  - Living far from the city and commuting



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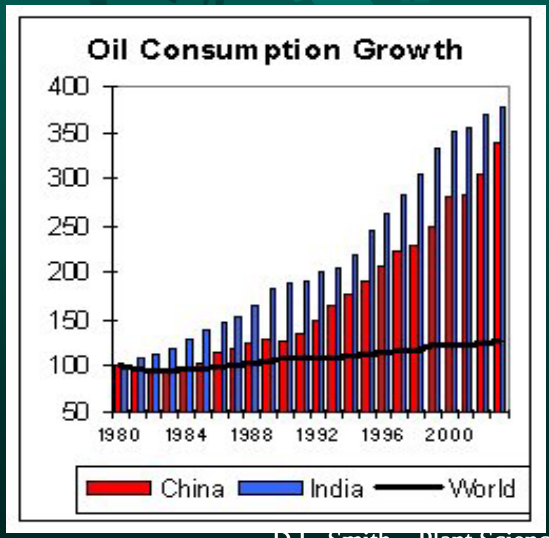
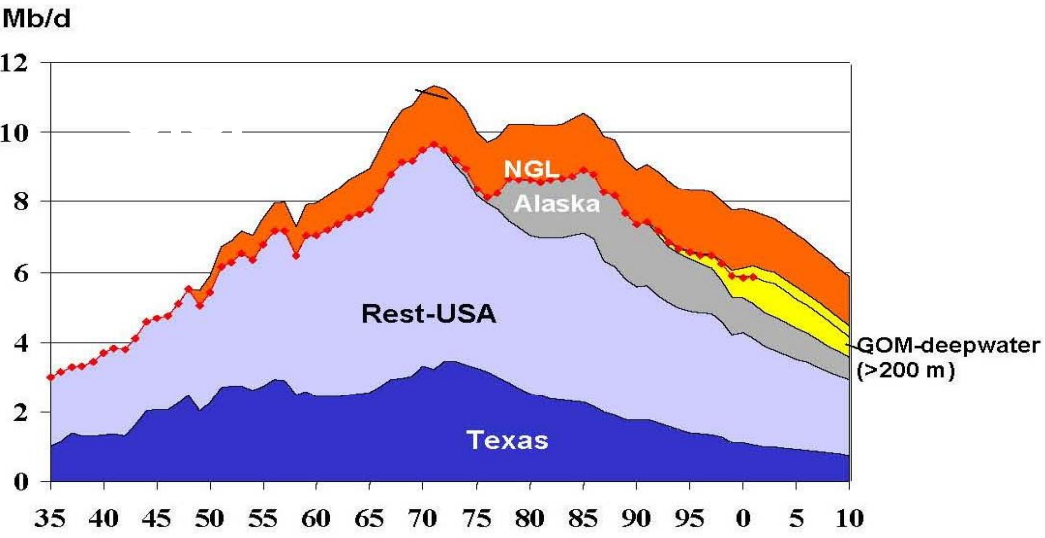
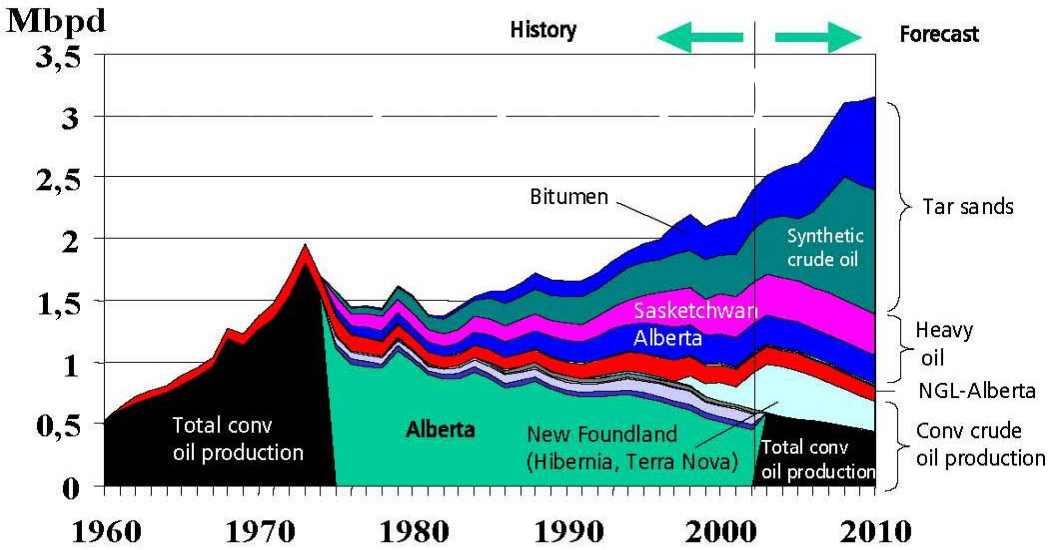
Energy Limitation:

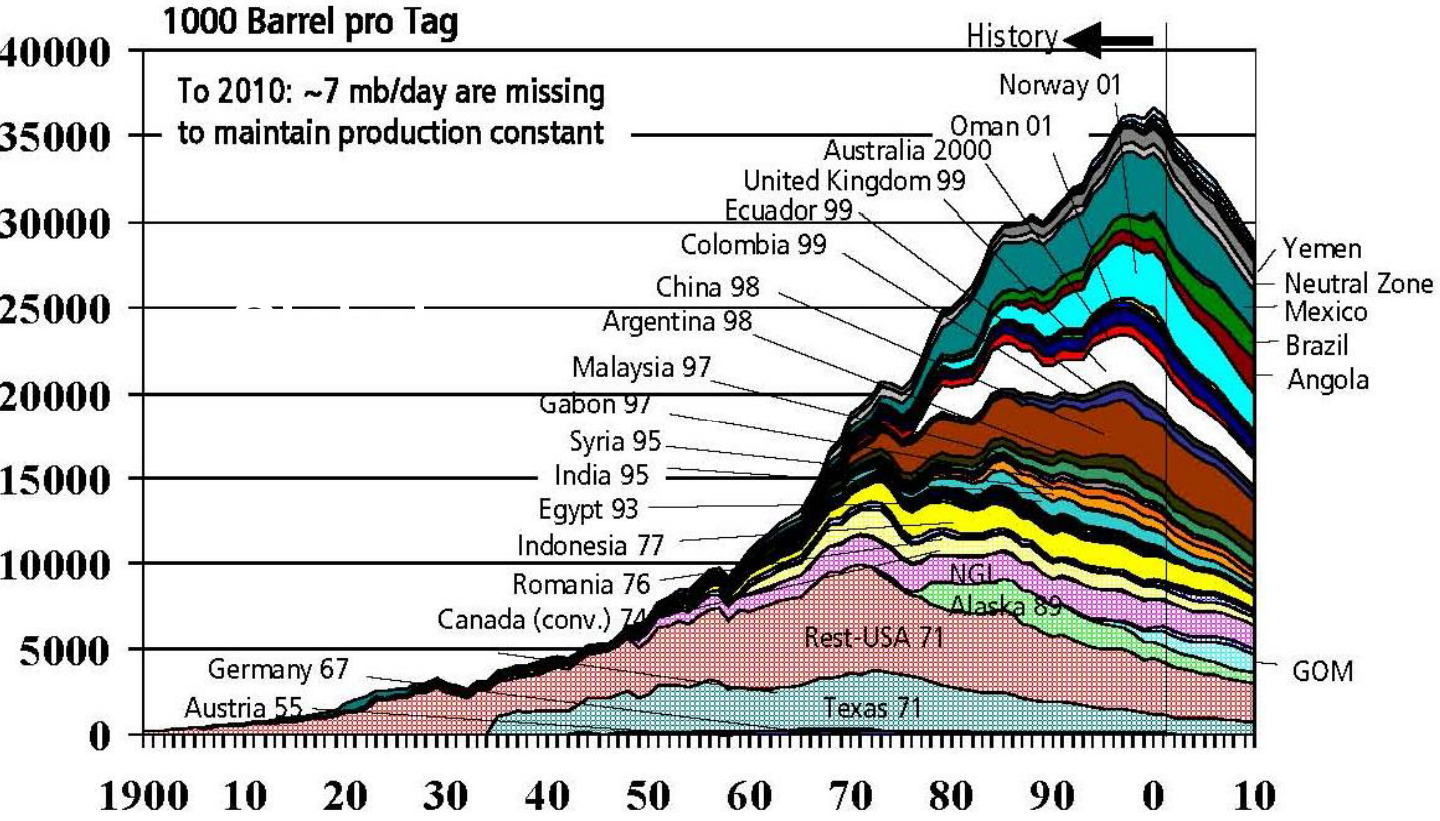
Pressures on Fossil Fuels

- The rate of fossil fuel consumption is rising in “developed” countries
- The rate of demand by China is rising dramatically
- India is now following the same trajectory as China









Global crude oil extraction has peaked or will peak within a few years.

NOTE: The recent strike in the Gulf of Mexico is 6 months worth of global demand.

Bio-fuels

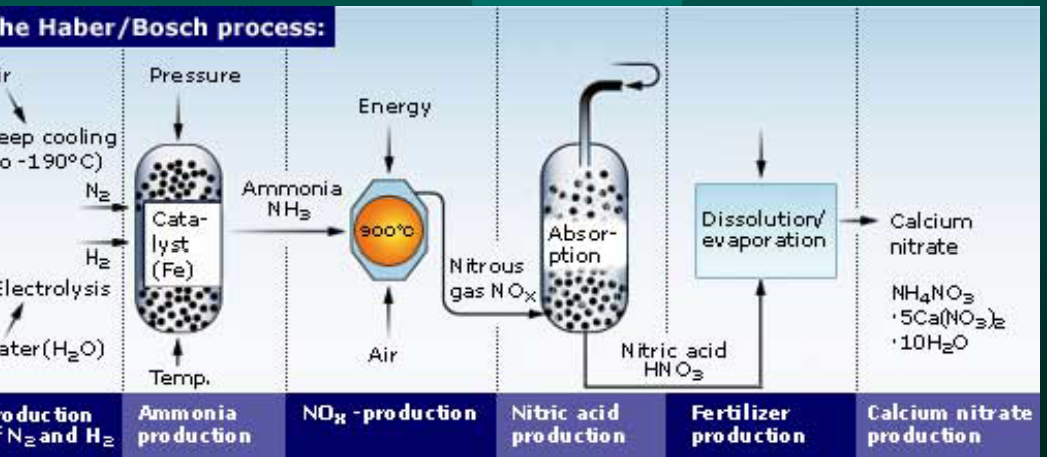
- Biomass for direct combustion
- Fermentation of sugar, starch and cellulose to ethanol or butanol
- Bio-diesel
- Bio-methane
- Hydrogen from bio-mass
- Food crops, non-food crops, plantation forestry
- Canada – 5% ethanol by 2010, 2% biodiesel by 2012
- Europe – 5.75% ethanol and biodiesel by 2010 (20% of cropland), 20% of each by 2020 (38% of cropland)

Biofuels and Food Price

- Food prices increased abruptly:
  - Increased population
  - Increased meat consumption
  - Waste:
    - Food is cheap (10 % of household income) so easily disposed of
    - In UK 30% of food is discarded, 40% of fresh fruits and vegetables
  - Increased energy costs (N fertilizer, transport)
  - Biofuels from food crops

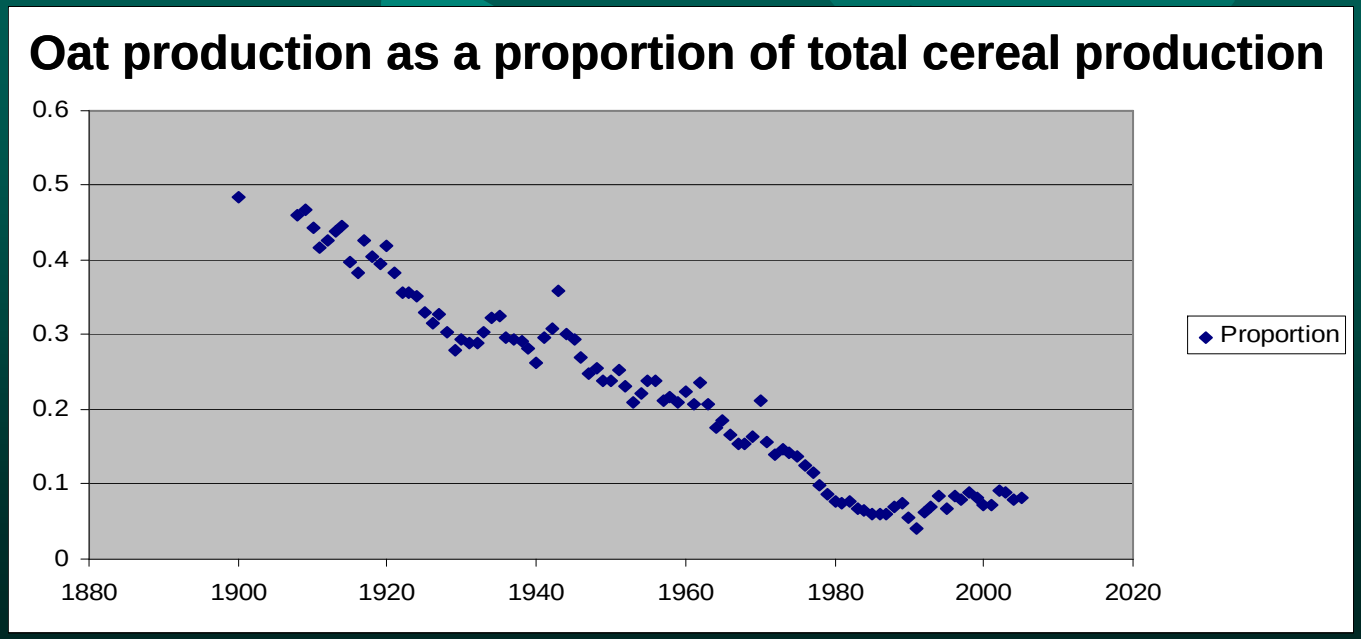
Energy Effects

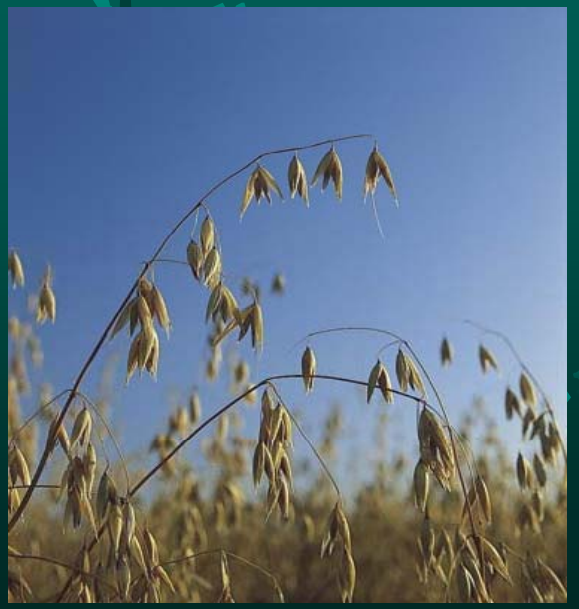
- Increased prices for key inputs
  - most notably nitrogen fertilizer
- Increased transportation and processing costs
- Farming must become energy efficient
  - Photovoltaics, waste into fuel



Back to the future

- At the beginning of the 20th century almost 50% of the Canadian cereal production was oat
- This was largely to be fed to horses
- The horses were our form of transportation
- This was a bio-based system





D.L. Smith – Plant Science

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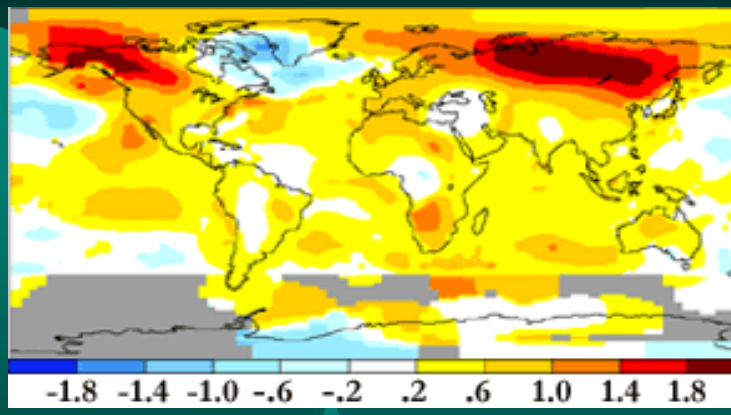
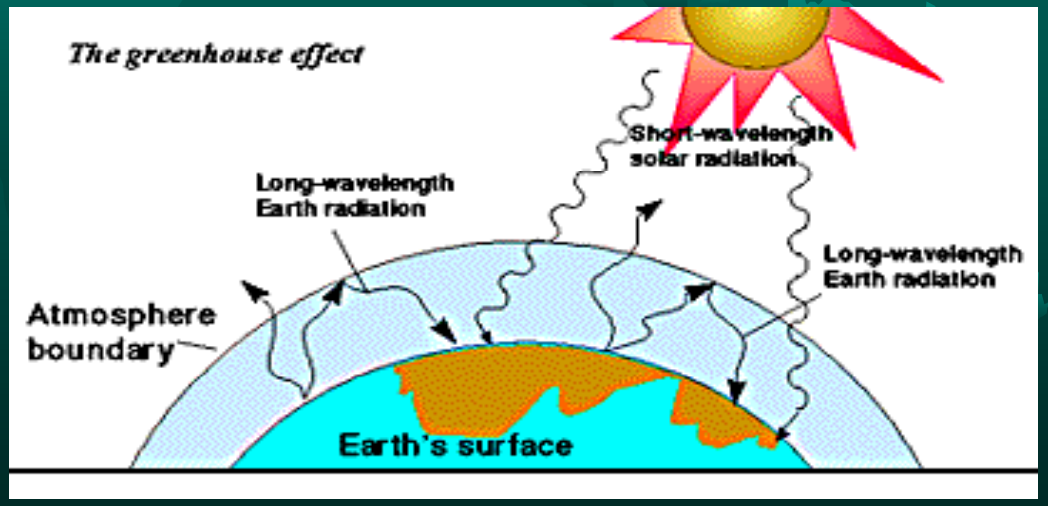
Climate Change

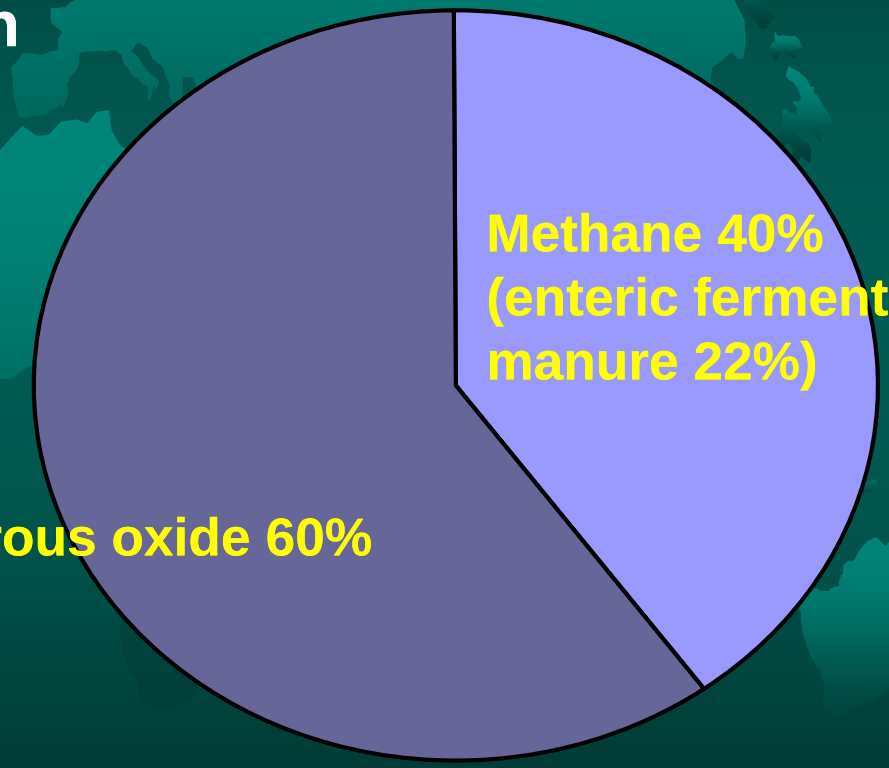
- Melting
  - Mountain glaciers
  - Greenland ice sheet
  - Arctic sea ice
- 5 to 8 ºC warmer in Canada
- Birds return sooner in spring & flowering sooner





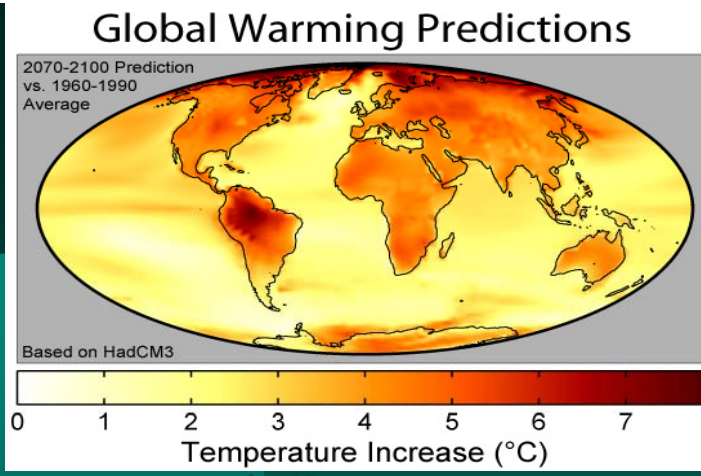
Agriculture Contributes

- 8.3% of Canada's total annual GHG production (EC 2004)
- 60 Mt of 726 Mt total
- Not including transportation fuel emissions



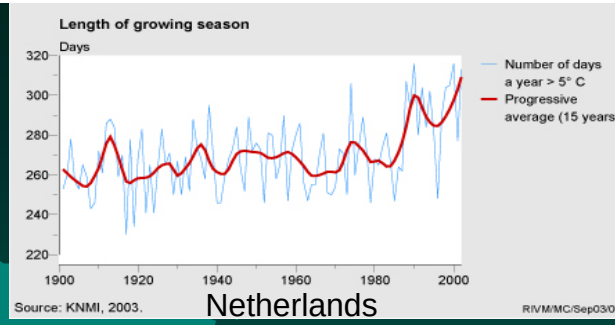
Canadian agriculture is a small net sink for CO_2 because of conversion to no-till.

It Will Get Warmer



- Models indicate that global average surface temperatures will rise by 1.5-4.5 ºC over the next 100 years.
- Increases will be smallest at the equator and greatest at the poles
  - In Canada, on the order of 5 to 8 ºC
  - In Europe small increases in the south, but larger in the north; has had some very warm summers recently and places like Germany have had largely snowless winters
- Night temperatures have increased more than day temperatures, winter more than summer

Seasons Will Get Longer



- At higher latitudes, where the length of the growing season is set by the time of last spring and first fall frosts the potential growing seasons will be longer
- Night temperatures are increased more than the day temperatures, and killing frosts occur at night, so the season lengths will increase faster than temperature means
- However, the higher night temperatures will increase the respiratory consumption of photosynthate disproportionately

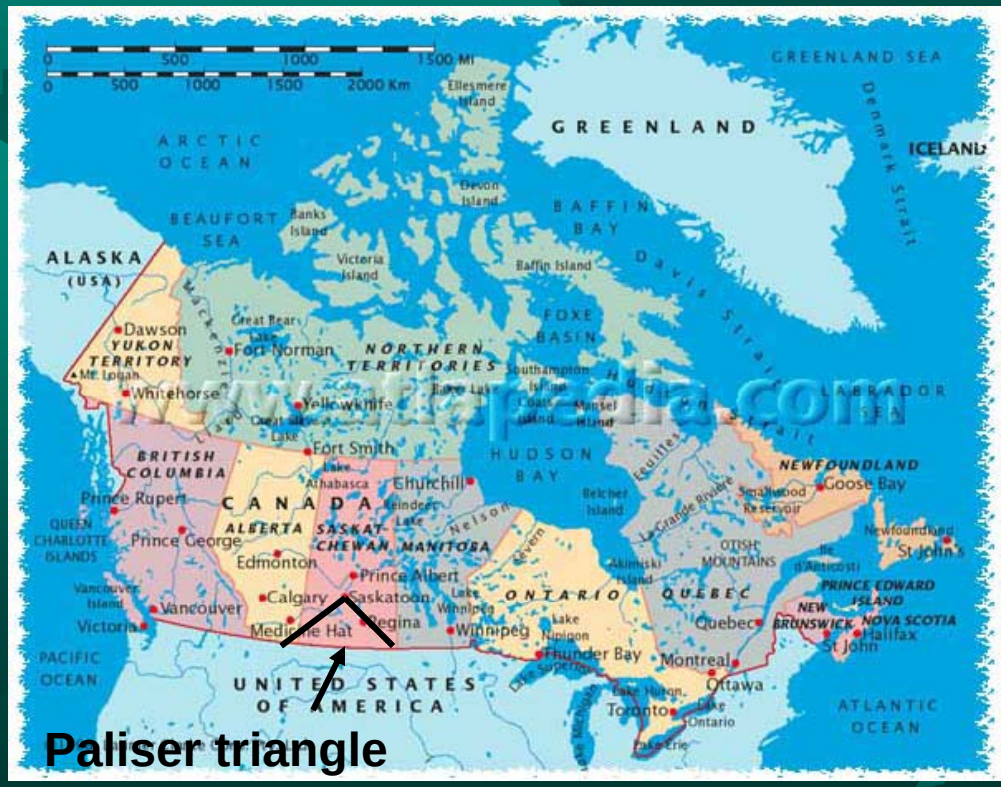
In General It Will Get Drier

- General circulation models predict decreased rainfall in some areas, and increases in others
- However, increased temperatures will lead to increased evaporation because of:
  - higher temperatures themselves
  - longer periods with unfrozen soil in northerly areas

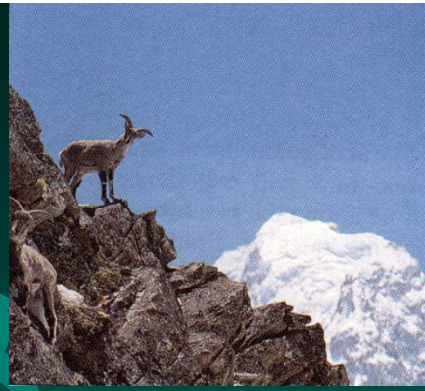
- Evaporation increases by ~ 5 per cent for each ºC of mean annual temperature.
- European wheat & maize: 1ºC warming (no change in precipitation) leads to a predicted 5% yield decrease.

Canadian Effects

- The Paliser triangle, in south central Saskatchewan, currently produces most of Canada's highest quality number 1 hard red spring wheat
- The general circulation models predict that if global warming goes ahead this area will only be suitable for livestock grazing
- In Quebec September temperatures have increased 3 ^{o}C in 30 years



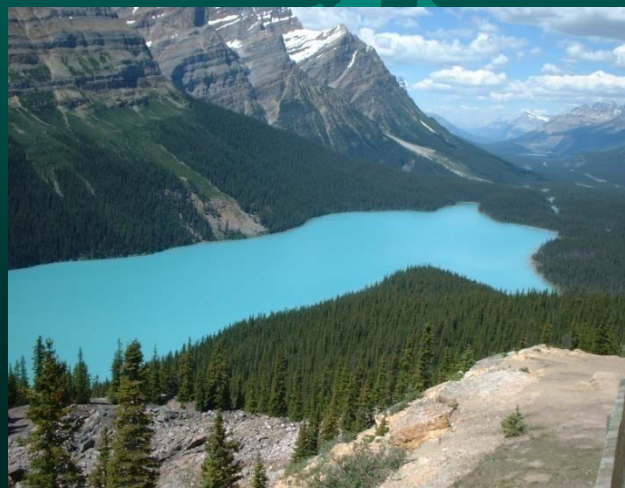
Glaciers and Rivers



- Glaciers around the world have retreated an average of about 30% during this century
- The 15,000 glaciers of the Himalayan mountains are retreating an average of 30 m per year, among them the Gangotri glacier that feeds the Ganges River
  - populations have developed based on this extra water availability for food production
- Many of these glaciers feed rivers whose waters are utilized for food production

In Canada Too

- A large amount of irrigated agriculture in Alberta is based on rivers from the Rockies
- The Peyto glacier in Alberta has lost 70% of its mass during the last few decades.
- This is happening to many glaciers in these mountains
- Now less water flowing into the rivers they feed, during the summer, and out onto the prairies where it is used for irrigation of crops

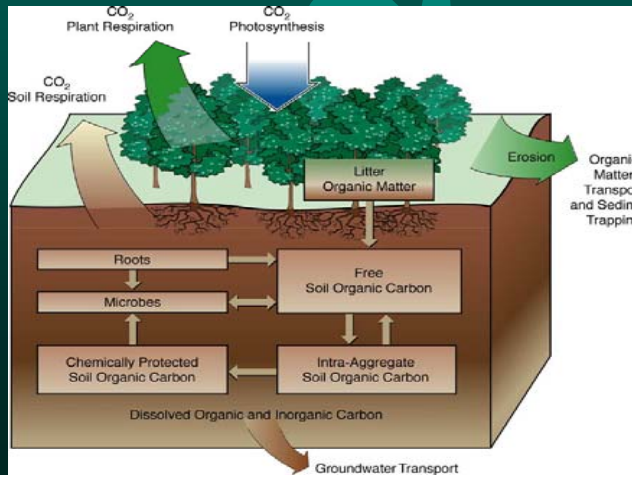


More Extreme Weather

- Drought and high temperature episodes will occur more often
  - rice could be pushed out of some parts of Asia
  - some semi-arid areas will become unable to support crop production
- More extreme El Ninos and more often
- Tropical storms will be more frequent, stronger and more destructive
- Weather variability is generally the greatest contributor to yield variability and there will be more of it

Changes in Soil Organic Matter

- Higher temperatures and, in some cases, higher rainfall levels, will accelerate soil organic matter break down
  - Low organic matter soils hold few nutrients and are more susceptible to drought
- Organic matter breakdown releases N that can contaminate waterways
- Where elevated CO_2 levels and better precipitation patterns occur there will be greater inputs of crop residues, increasing soil organic matter



Soil Erosion

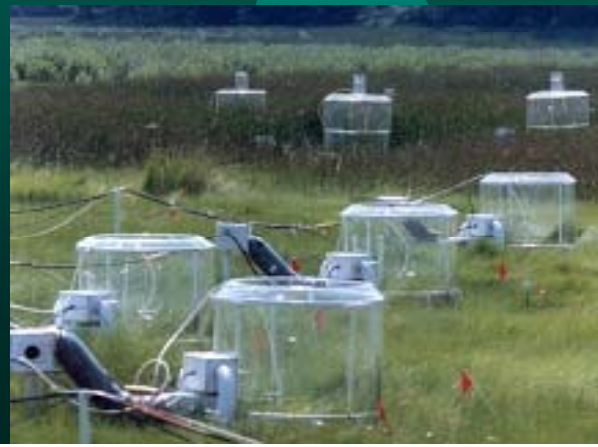
- In many areas soils will be drier
- Soil organic matter will be lower
- Increased equator-to-pole heat flux will mean greater average wind speeds
- This will increase the potential for wind driven erosion by an estimated 20 to 30%

Sea Level Rise

- Most models predict a sea level rise of about 50 cm by 2100
- This will lead to the loss of agricultural land due to flooding by sea water and salinization in areas that are newly coastal
- River deltas are some of the most productive agricultural lands
- Bangladesh, some island nations and perhaps the Netherlands will be severely affected

Plants and CO_2

- Photosynthesis is CO_2 limited, so more CO_2 increases the rate, and therefore plant growth
- Some plants partially close their stomata so that photosynthesis is not increased, but water use efficiency is.
- C_3 plants (more in the temperate zones) benefit more than C_4 plants (more in the tropics).
  - Photosynthesis ratios (555 ppm CO_2/330 ppm CO_2) for soybean, wheat and rice, and maize were 1.21, 1.17, and 1.06, respectively.



Changes in Crop Quality

- In general, the higher levels of carbon (CO_2) will lead to crops (seeds or, in the case of forages, leaves and stems) that are higher in carbon and lower in protein.
- On the other hand, material with higher sugar contents will make better silage.

Stimulation of Nitrogen Fixation

- Increased CO_2 levels will increase the amount of photosynthate available inside the plant for N_2 fixation.
- In areas where climate change conditions lead to increased growth of legumes, this will lead to increased N demand, and increased N fixation.

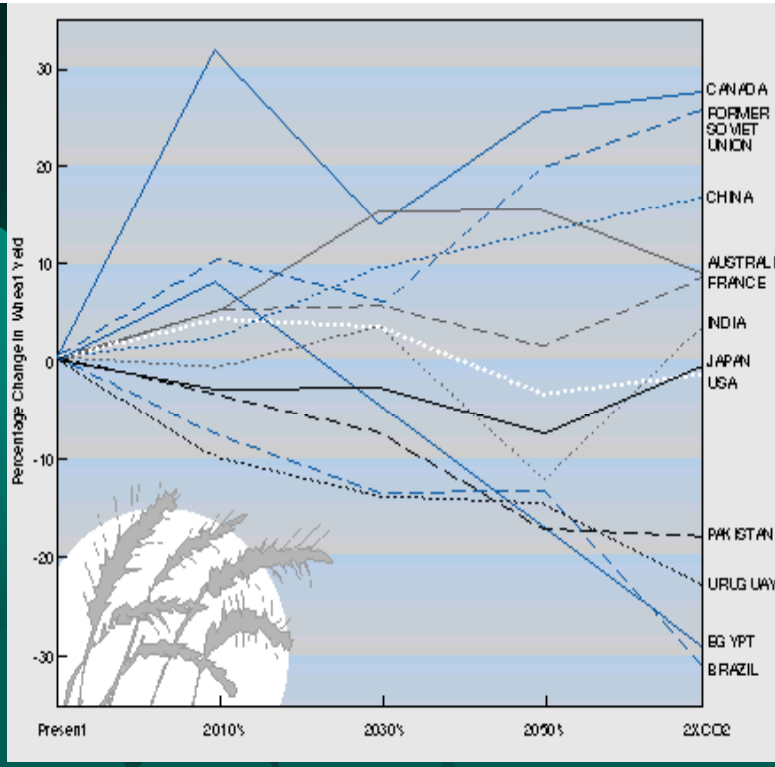
Pests Will Move

- Weeds, diseases, insects will spread from warmer areas into formerly cooler ones.
  - Warmer winters allow overwintering of larvae in areas where this was not possible.
  - Increased number of generations possible.
  - So, longer time for development and feeding and a wider range of pests
  - European Corn Borer 165 – 500 km northwards with a rise of 1^{o}C.
- Greater wind speeds will assist movement of spores.
- Similar effects for livestock pests.

Grassland species will change

- Where dry hot areas become more so there will be a shift from C_3 to C_4 species
  - Generally the grazing quality of C_4 species is lower.
- In temperate-moist areas increasing CO_2 will favour C_3 over C_4 species.

Estimates



- Most models show modest decreases in world food production due to climate change.
  - There will be increases in productivity in many temperate areas.
  - Tropical developing countries, those most directly dependant on agriculture, will suffer decreases of 10 to 20 %.
  - In Europe, increases in the north, possible decreases in the south

How Big A Temperature Effect?

- Lower temperature increases (on the order of 2ºC) have small overall effects, negative in some areas and and positive in others
- Larger temperature increases (on the order of 4ºC) tend to cause clear decreases

Adaptations

Living With It

Alternative Crops & Cropping Systems

- More C_4 crops can be grown in temperate areas
- Eg.: Although the current geographical boundary (with regards to temperature) for ripening maize excludes most of the UK, a temperature increase of 0.5 ºC would allow maize cultivation across southern England.

- Winter wheat, with its higher yield potential, could move into areas where spring wheat is now produced
- Cultivars with longer times to maturity (and therefore greater yield potentials) can be grown
  - This will bring management changes such as earlier seeding
- In the mid latitudes the increase in season lengths may be sufficient to allow the adoption of double cropping practices

Fertilizer Use Will Change

- In areas where crop production potential is increased higher levels of fertilizer application will be required to meet the potential
- The increases will be greatest for N

People Will Move

- Northward migration of crop production
- Will require the development of rail infrastructure in the north, and probably the ability to ship more grain out of the Port of Churchill
- The new area to the North is as large as the one going out of production, but the soils are younger and less fertile

Tillage Systems

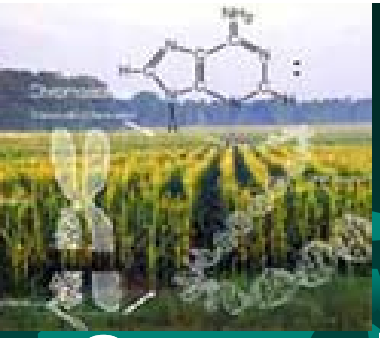
- With warmer soils no-till and minimum-till systems will become more feasible
- These systems will store soil water better, and store soil carbon better, with the latter leading to less potential for soil erosion

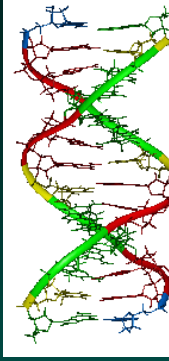
Pesticides

- There will be a greater need for applications of various pesticides (insecticides, fungicides, herbicides)
- Genetically modified crops may help out in this area

Irrigation

- In some areas there will be the potential to expand the use of irrigation
  - infrastructure costs
- However, in others, as river flows decrease, irrigation use will decrease
- The competition between urban and agricultural uses of water will be increased
- Competition among nations will lead to warfare





Genetics

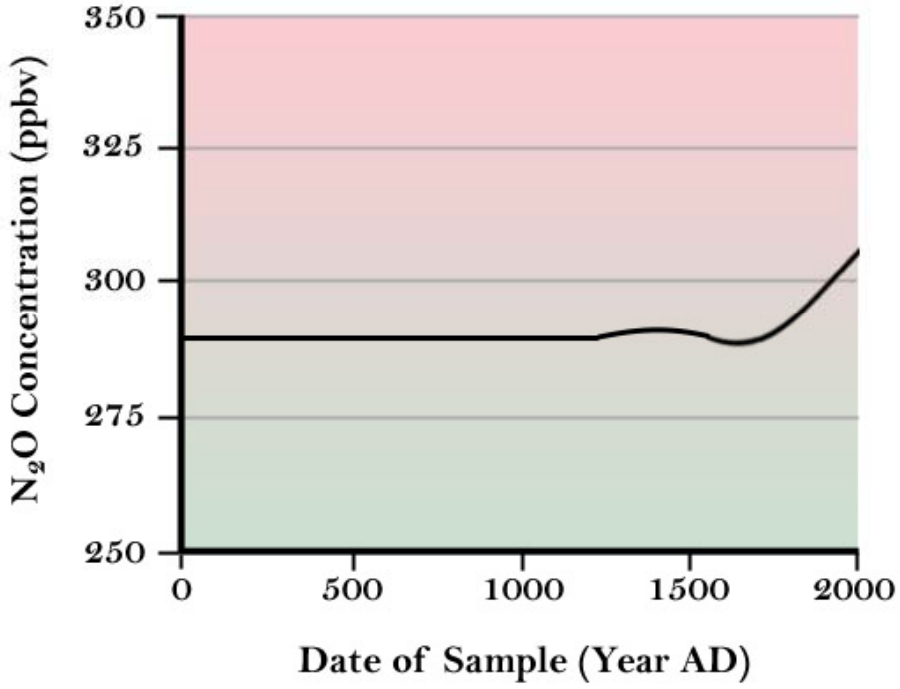
- Conventional breeding and genetic engineering can develop plants more tolerant of heat, drought and pests, and that take more advantage of elevated CO_2 levels
  - For crops, a drought tolerant genotype experiences less yield reduction in the presence of drought stress
- Plants better at sequestering carbon in soil and/or producing materials that substitute for fossil fuels could be developed
- However, water is involved in plants to an even greater degree than animals, so many genes involved:
  - 99%of water absorbed is lost by transpiration
  - crop uses ~10,000 t ha^{-1} $season^{-1}$
  - Growth is based on water to expand cells

Green Crop Network

McGill

Mitigation

- Soil carbon sequestration
- Reduced nitrous oxide emissions
- Higher photosynthetic rates
- Biofuels



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Environment

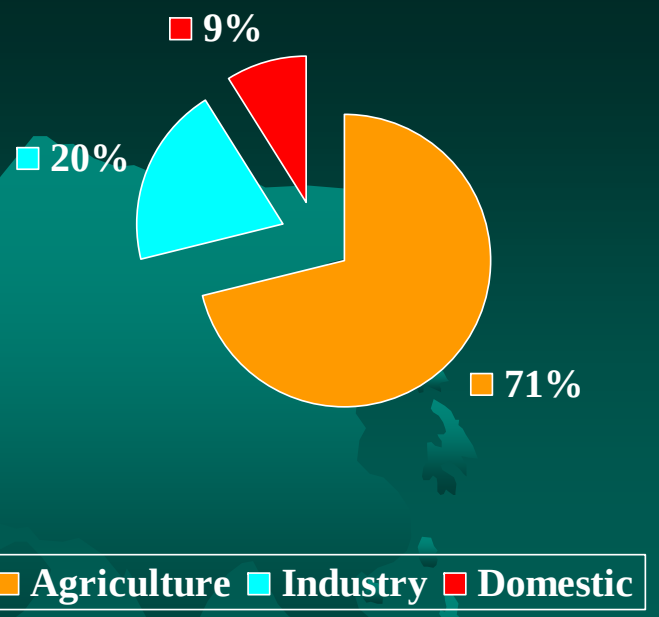
- There is a need for sustainability
- Agriculture is a major non-point source of pollutants
- Agriculture is a major consumer of key resources
- It is the sector with the largest environmental footprint, just because it covers such a large area

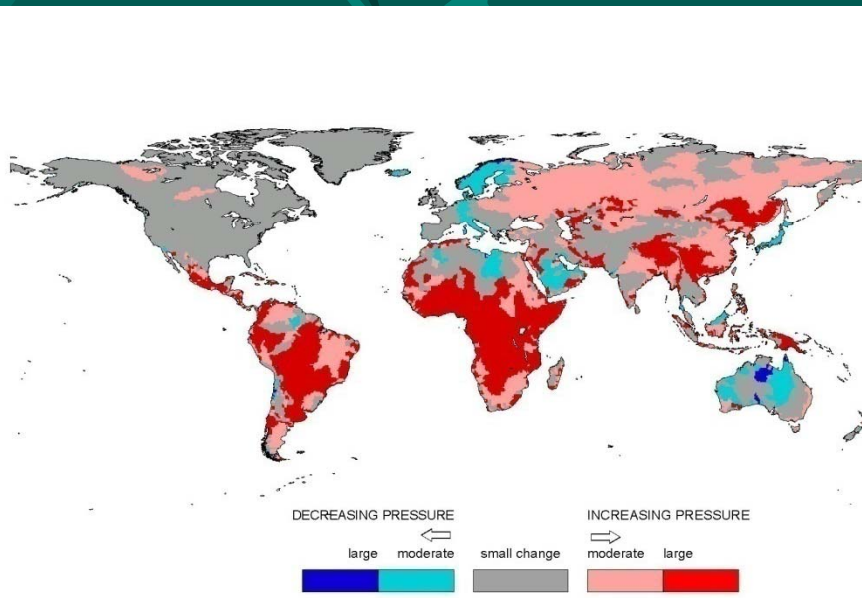
Dead Zones – Nutrient Loss

- Nutrient loads (principally nitrogen) lead to eutrophication in lakes, and now areas of the open ocean
- Results in anaerobic conditions and death of fish, etc.
- Many assocaited with cities, but some with agriculture
- Also in the Baltic
  - 1 billion of tonnes N yr^{-1}

Water

- Agriculture is a major user
- Will be competition from urban use
- Aquifers being pumped out
  - Ogallala
- Land salting up
- Proportional use by agriculture varies:
  - N. Europe 4%
  - S. Europe 44%
- Many rivers no longer reach the sea during the summer (eg. Yellow)



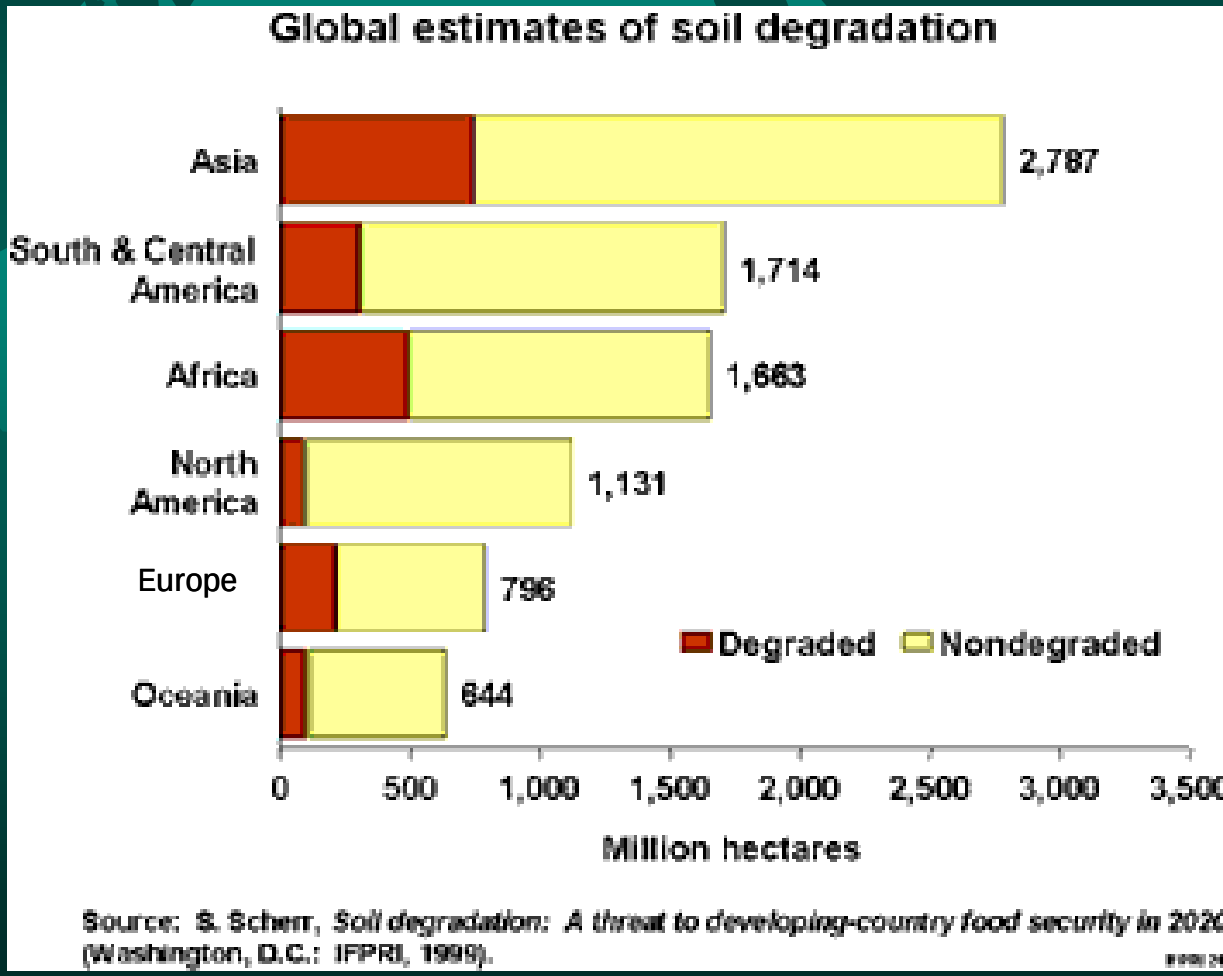


Biodiversity

- Expansion of agricultural land has lead to a large loss of habitat and biological diversity
- The most notable example of this is the Amazon basin where land is being cleared for cattle and soybean production
  - Loss of habitat for other organisms
  - In Europe there has been a 30% reduction in farmland butterflies over the last 20 years
- In addition, pesticides may kill non-target organisms, leading to decreased biodiversity

Soil Degradation

- **Erosion**
  - Deforestation and plowing of hillsides
  - Demand for fire wood and food production area
- **Salinization and water logging**
  - Irrigation effects, inappropriate use of water



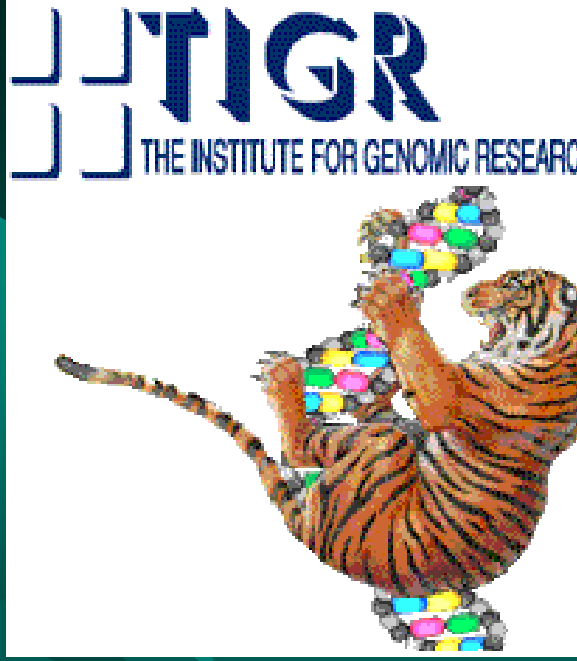
Structure

- Food
- Energy
- Climate change
- Environment
- Solutions

Genetically modified organisms

- Have great potential
- The next step, follows plant breeding
- Improved crop efficiency and nutrition
- However, concerns about:
  - Environmental problems (gene flow)
  - Allergens in food
  - Who owns the genes?

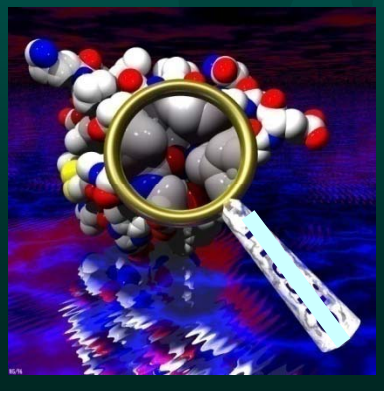
Genetics



- Started the last century with the rediscovery of Mendel's work (traits discretely inherited)
- Started this century with ability to move genes between organisms, and sequencing genomes

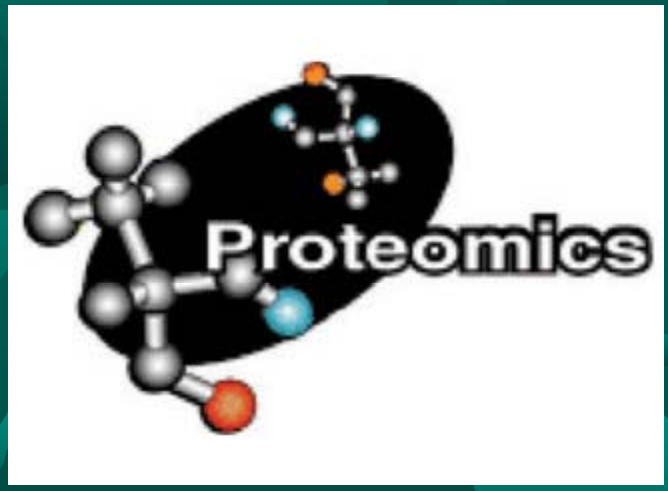
The Novelty

- In many ways it is the golden age of biology
- For the first time we will begin to work from the informational bottom (DNA) up, with all the information in hand at the basic level



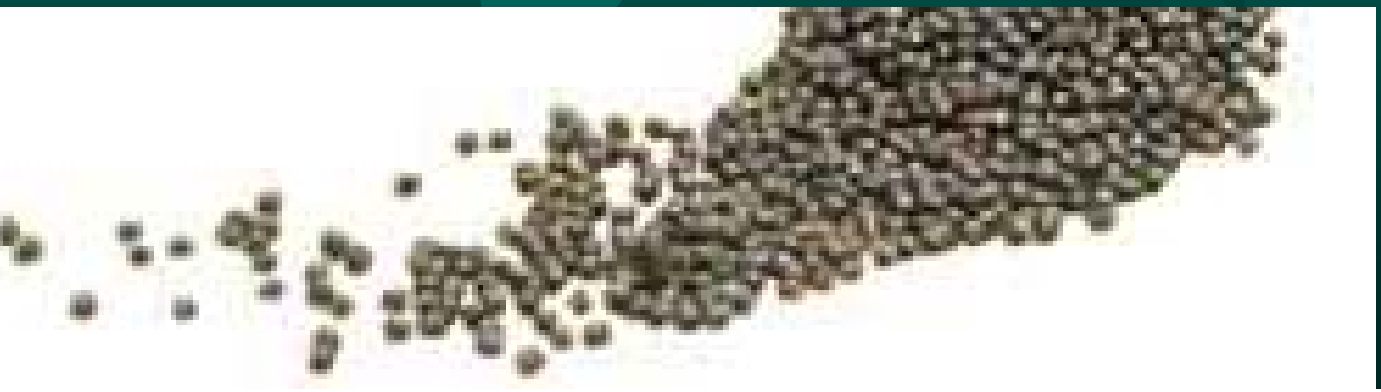
Tools For The 21st Century

- Molecular biology
  - genome
  - transcriptome
  - proteome
  - metabolome
  - phenome
  - environome



In North America

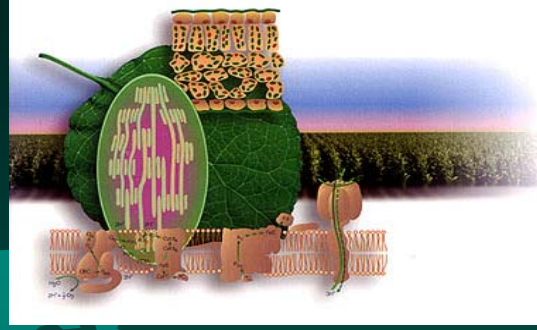
- Much of the corn, soybean, cotton and canola produced in North America have been genetically modified by transgenic techniques



GMO contributions

- Not so much on the yield side, at least not initially
- More on the environmental side
- Development of insect resistant crops in China has resulted in a reduction in the incidence of pesticide poisoning of farmers

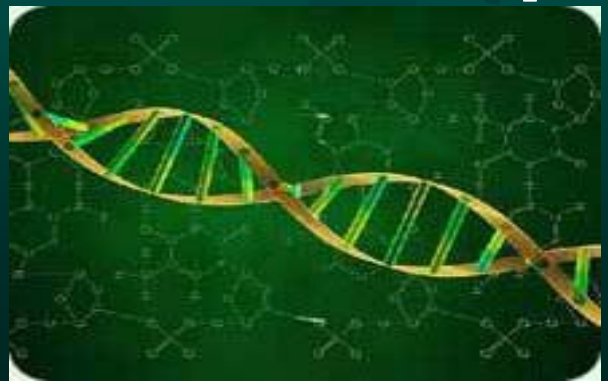
The Goals



- Improved photosynthetic rates of crops
- Improved pest and stress resistance of crops and livestock
- Improved water use efficiency of crops
- Nitrogen fixing cereals
- Increased efficiency of livestock growth
- Improved crop quality
- Reduced crop storage losses
- Functional foods

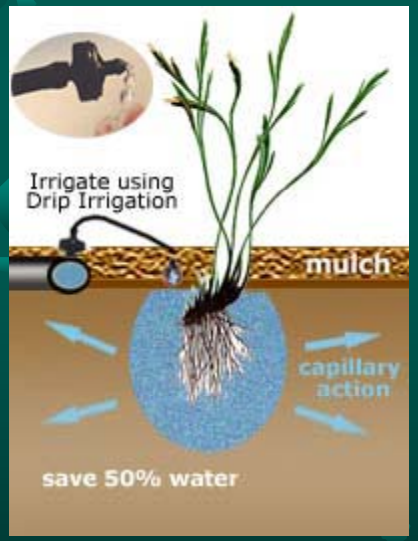
What Has Changed

- In many ways these have been the goals of plant and animal breeders all along
- New methods will allow precise identification of where the changes could occur and their potential effects



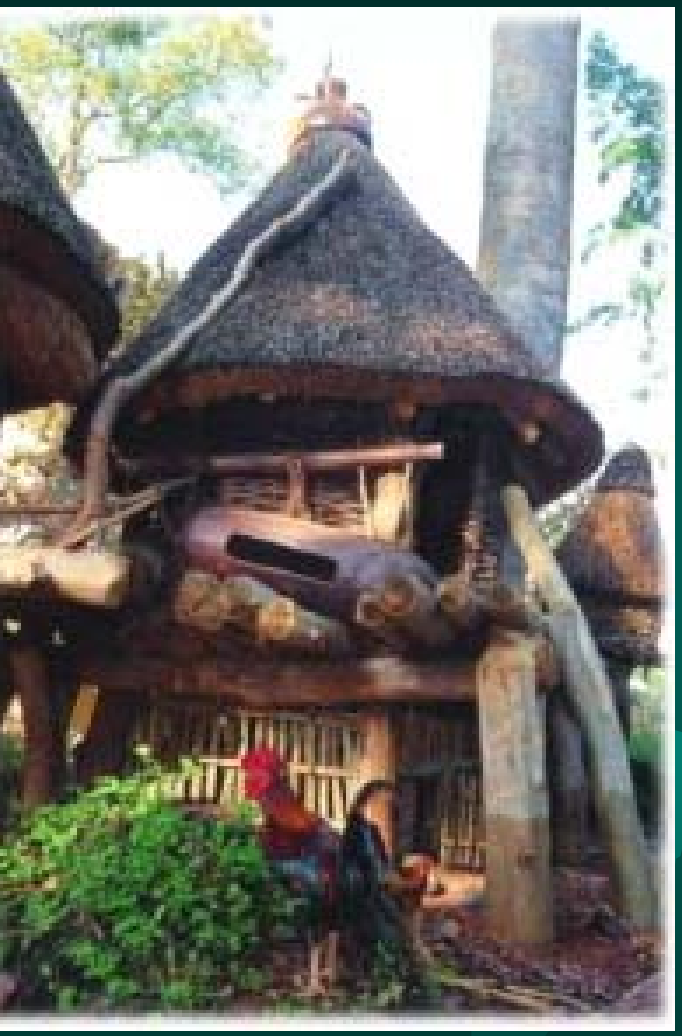
Some More of the Same

- There will be continued plant breeding
  - Selection for higher yield is key
- There will be some additional improvements in conventional management areas
  - Expansion of drip irrigation
  - Improved management in Russia and Ukraine



Veg-Meat

- Engineer plants to produce meat quality protein
  - High concentration
  - Amino acid balanced
- Perhaps even meat texture
- Solves the trophic level problem
- Less pressure on crops



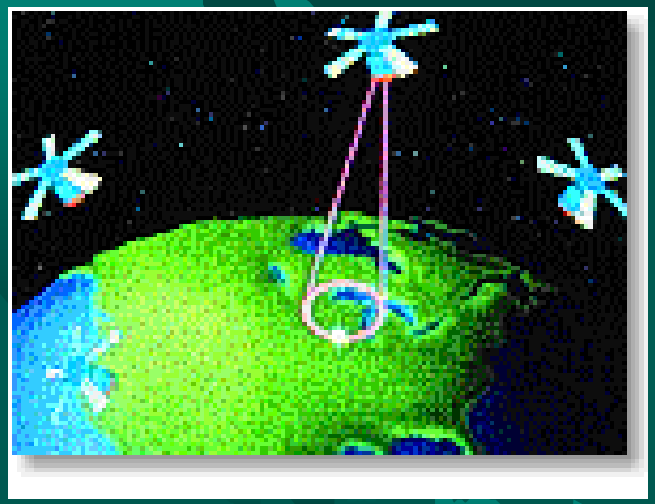
Storage

- Losses in storage can be a very large issue
- In the tropics over half of the harvest can be lost in storage
- Genetics?
- Engineering?

New family size granery.

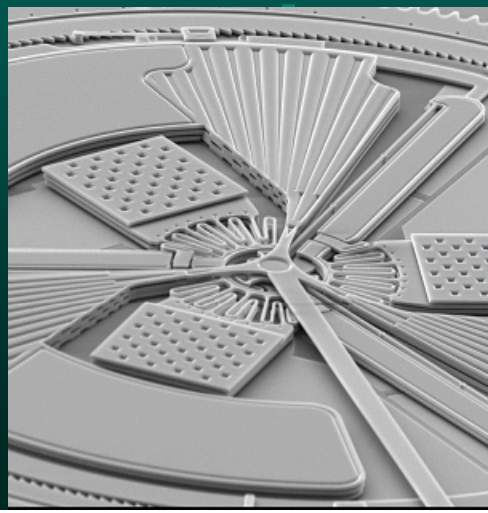
Precision Agriculture

- Is very precise (± a cm)
- Allows more efficient use of fertilizers, biocides and seed
- Assessment of data in images can determine areas of nutrient deficiency, water stress, weed presence
- Real time images are coming
- Is becoming very accessible (inexpensive) and integrated with the internet



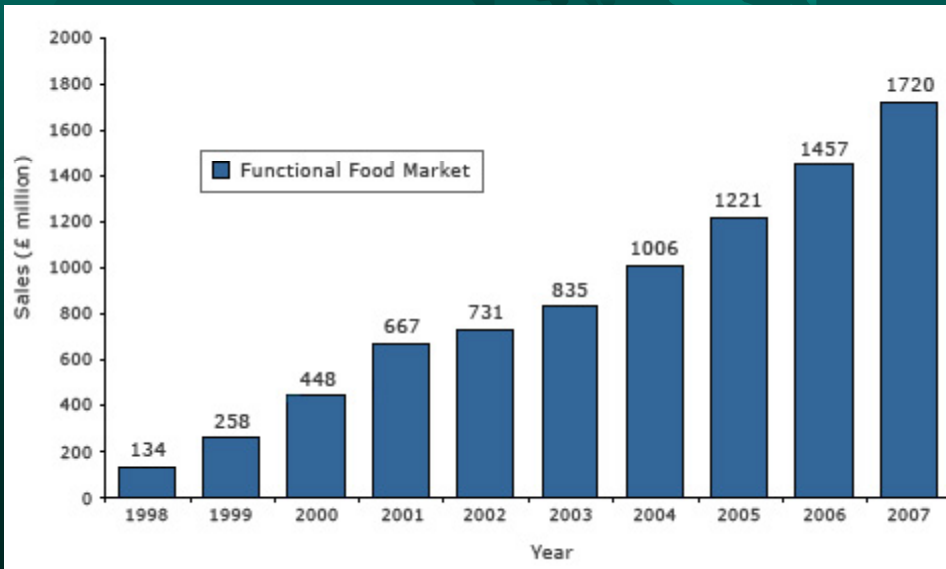
Nanotechnology

- Materials
  - Eg. paints that self clean
- Sensors to detect disease organisms and toxins
- Nano-electro mechanical systems (NEMS)
  - Radio frequency identification
  - Tracking, including food

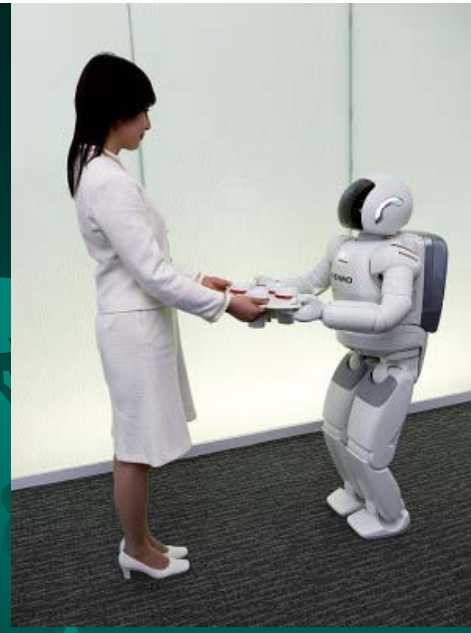


Functional Foods

- Specific elements added
  - Eg. vitamins, nutraceuticals, pharmaceuticals
- Remove detrimentals
  - Eg. allergens



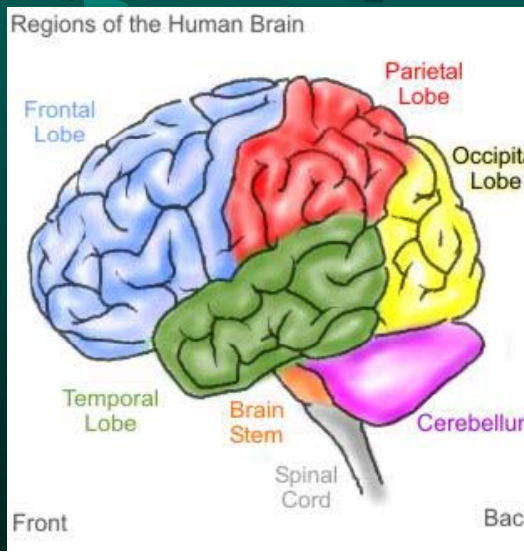
Robotics and AI



- Improved robitics in general
- Application to crop production, harvesting and processing
- Fitted into precision agriculture
- Application of brain understanding
- Facilitates intercropping

The Brain

- Understanding perception can allow better perspectives on subjective sensing of food products
- Develop food that is more “pleasing”
- Both umami and lipid receptors discovered in recent years



Ecological Systems Research

- Understanding the interactions between all aspects of an agro-ecosystem
- Modeling
- Better assessment of environmental and economic aspects of agricultural production methods

Exploitation of Biodiversity

- As our understanding of complementarity among crop species improves we can develop optimal intercrop systems
- With the development of things like machine vision the equipment restrictions to these systems will be removed

Climate Cycles

- Improved understanding of semi-regular occurrences such as El Ninos may allow farmers to develop several cropping systems, for different sets of recurring conditions, and switch to the appropriate one when a given climate regime is forecast

The End!

Biorefinery Compatibility

- Typically, pertro refineries make as much from other high values chemicals as from energy materials
- This will almost certainly also be the case with biorefineries
- Because of genetics we can alter the amounts of specific high value materials in plant feedstocks
  - Chemical products (low-volume / high-value)
  - Platform chemicals (high-volume / low-value)
  - Examples of high value chemicals are: lubricants, inks, coatings, waxes, personal care products, polyols, esters, fatty acids, surfactants, cleaners, biocides and placticizers, 1,3 propane diol.