Climate Change

& Crop Productivity

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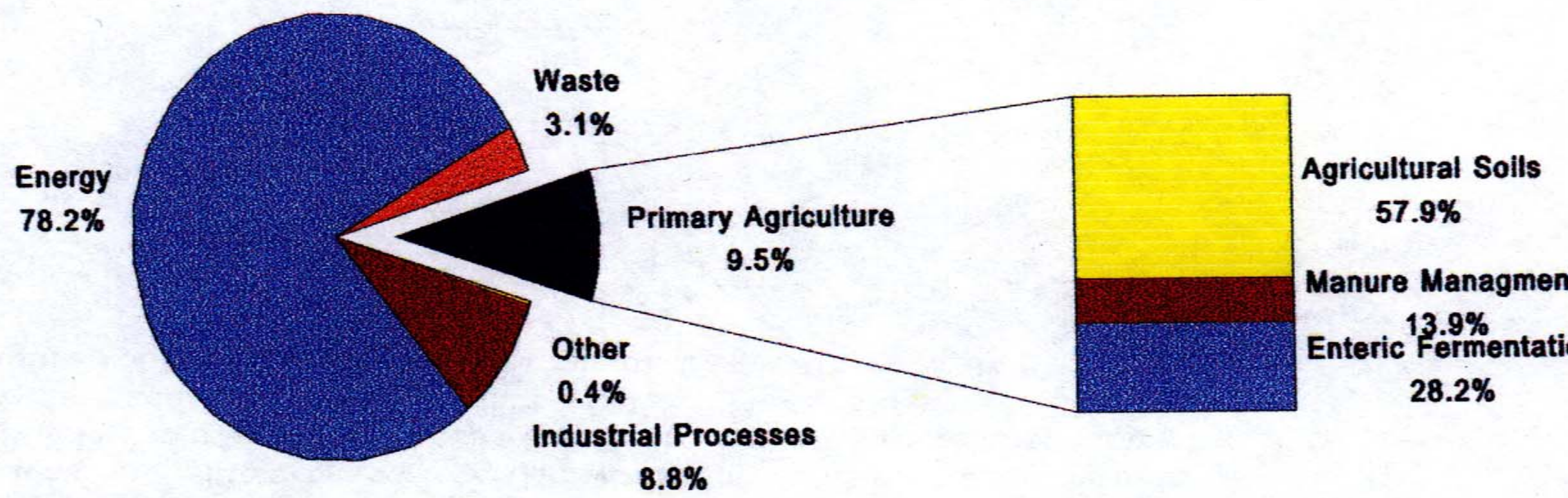
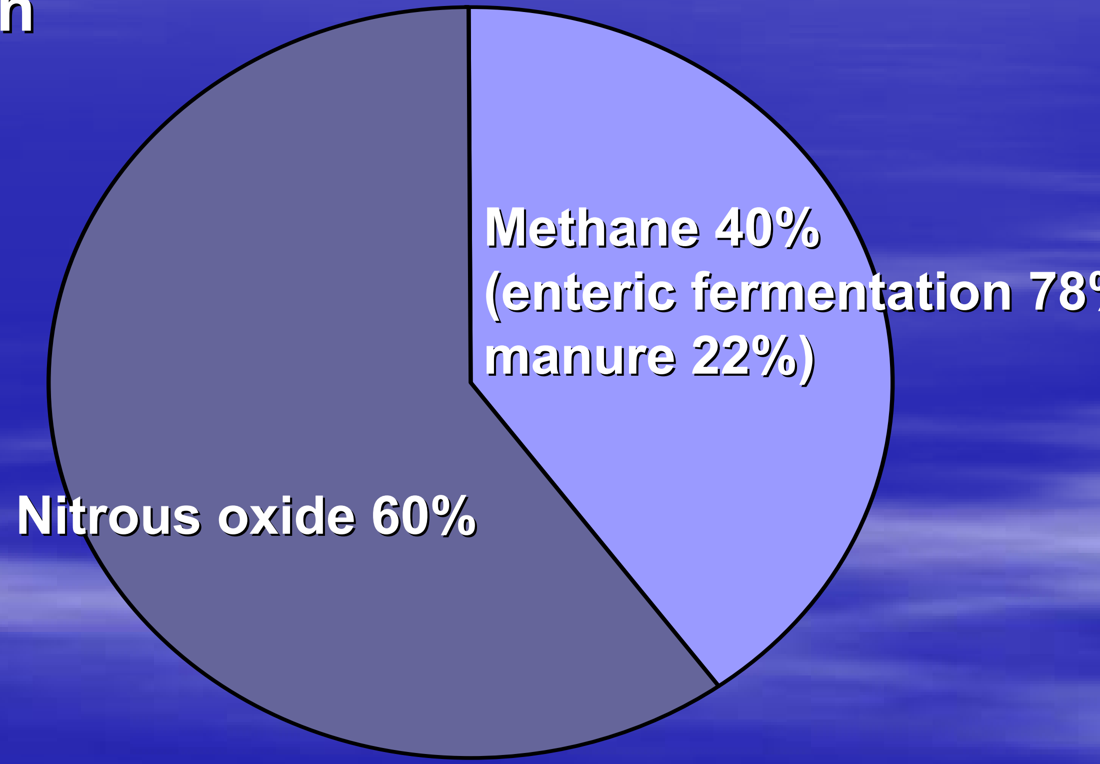
Agriculture as a Contributor



Agriculture Contributes 60 Mt of 726 Mt total

8.3% of Canada's total annual GHG production (EC 2004)

Not including transportation fuel emissions



Heat trapping:

CO_2 = 1

CH_4 = 21

N_2O = 310

CO_2 - Deforestation

During the last two millenia extensive areas Europe and Asia have been deforested

In North America most of this has occurred during the last 300 years

– From about 1700 to 1900, the clearing of northern hemisphere forests for agriculture was the largest agent of change in the carbon cycle.

The process is ongoing is places such as the Amazon Basin

Much of the deforestation is associated with creating land area for food production

CO_2 - Declining soil organic matter

- Tillage aerates soil enhancing oxidation of organic matter
- Unless organic matter inputs (crop residues) are increased under agriculture soil organic matter will decrease
- The organic matter is lost as CO_2
- Warmer soil temperatures will accelerate this

H_4 - Rice Paddies

- Soils are anaerobic
- Organic matter break down leads to methane production
- Usually more than half of the methane escaping from the soil is oxidized to CO_2 in the upper few mm of soil and the water
- The methane diffuses out of the soil and also ou hrough the plants via aerenchyma (major route he atmosphere)
- Just over half of agricultural emissions

CH$_4$ - Livestock

- Ruminant livestock (sheep, goats, camel, cattle, buffalo, etc)
- Much is produced in the gut and is released by respiration, burping, flatulence (the greatest part)
- There are additional, and significant releases fro decomposing manure (a smaller amount)
- Just under half of current agricultural emissions

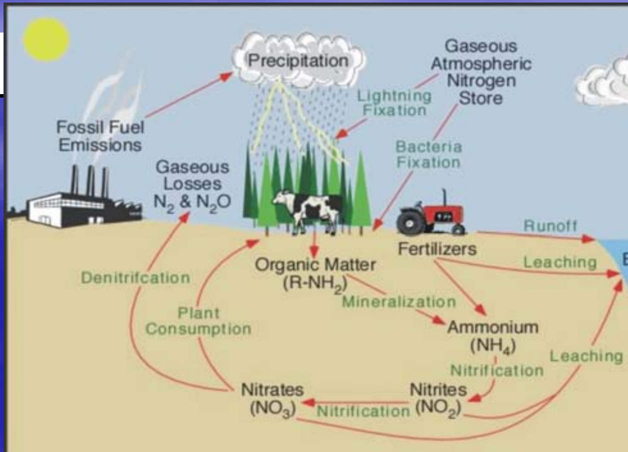
Nitrous Oxide

- Denitrification
- Nitrification (small amount)

- Also contributes to the destruction of ozone

Denitrification

- The end products of this process are N_2 and N_2O
- Soil mineral N (from fertilizers or organic matter) can be denitrified when soils become anaerobic
  - eg. when there are periods of intense rain over several days or at snow melt in the spring
- Warmer soil temperatures will accelerate denitrification



Options for Mitigation

Reduced N_2O emissions

C sequestration into soils

Biofuels production

Aided by increased plant productivity

Impacts

It Will Get Warmer

- Models indicate that global average surface temperatures will rise by 1.5-4.5 ^{o}C 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 ^{o}C
- Night temperatures have increased more than day temperatures

Seasons Will Get Longer

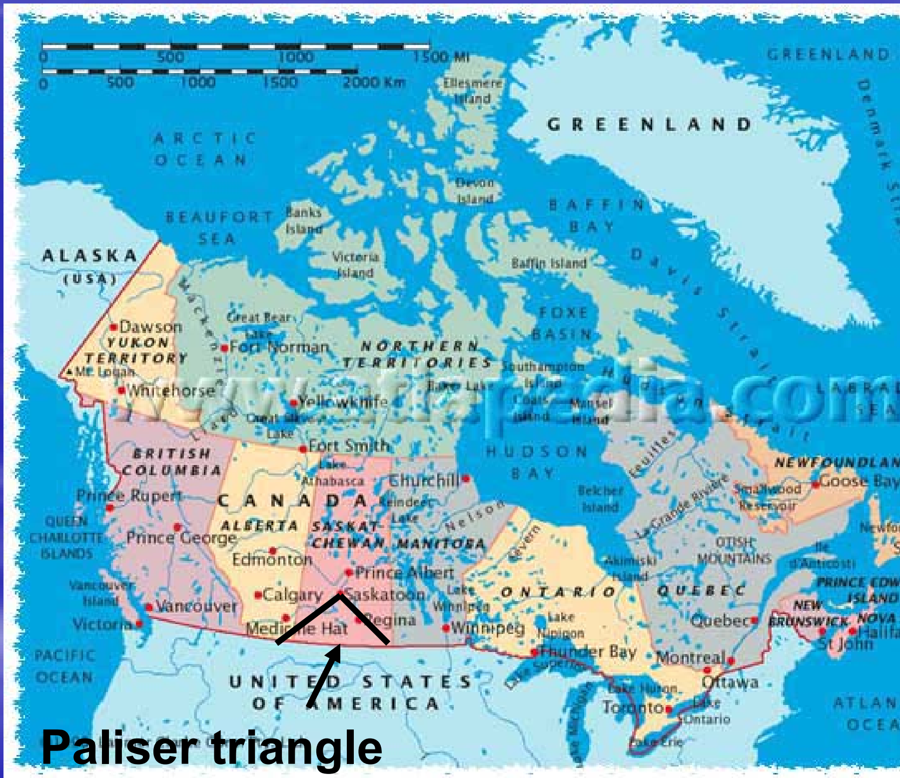
- At higher latitudes, where the length of the growing season is set by the time of last spring and first fall frosts the potential growing seasons will be longer
- Night temperatures are increased more than the day temperatures, and killing frosts occur at nig so the season lengths will increase faster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

Canadian Effects

- The Paliser triangle, in south central Saskatchewan, currently produces most of Canada's highest quality number 1 hard red spring wheat
- Some of the general circulation models suggest that if global warming goes ahead this area will only be suitable for livestock grazing



Glaciers and Rivers

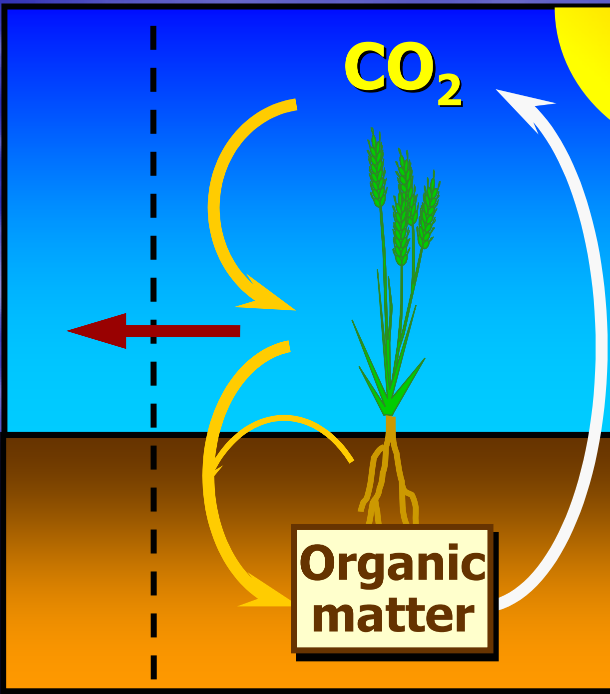
- Glaciers around the world have retreated an average of about 30% during the last 100 years
- Himalayan glaciers (15,000) retreating at 30 m per year
  - populations have developed based on this extra water availability for food production
- Peyto glacier in the Rockies is now only 10% of the size it was 100 years ago
  - Flow into the Bow river has declined & irrigation based crop production along it (Alberta) is affected

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
- We will probably have more extreme El Ninos and more often
- Tropical storms will be more frequent, stronger and more destructive

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
- Where elevated CO_2 levels and better precipitation patterns occur there will be greater inputs of crop residues, increasing soil organic matter



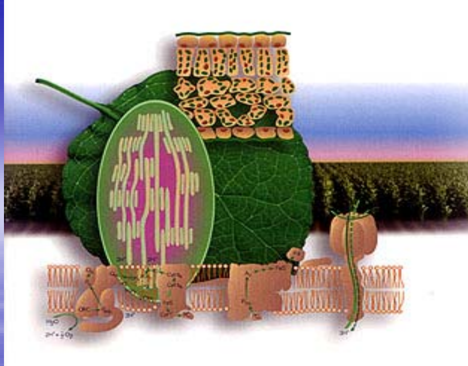
Soil Erosion

- In many areas soils will be drier
- Increased equator-to-pole heat flux will mean greater average wind speeds
- Soil organic matter will be lower
- 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

Plants and CO_2



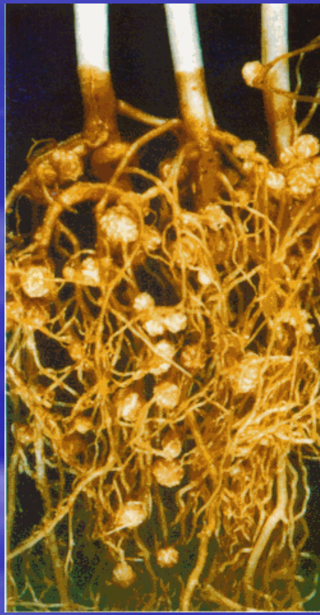
- Photosynthesis is CO_2 limited, so more CO_2 increases the rate, and therefore plant growth
- Some plants partially close their stomata so that photosynthesis is not increased, but water use efficiency is.
- C_3 plants (more in the temperate zones) benefit more than C_4 plants (more in the tropics).

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.



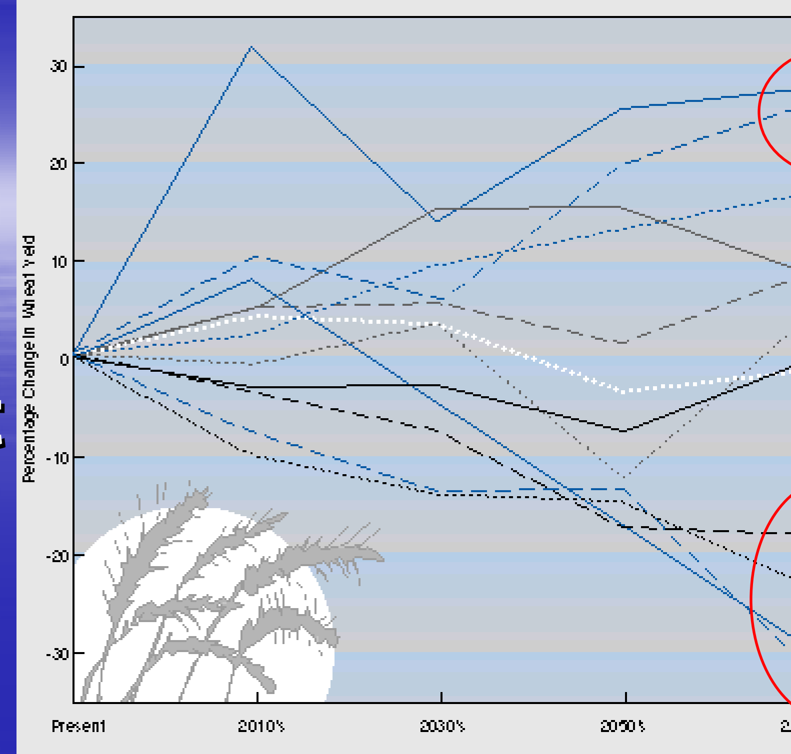
Pests Will Move

- 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.
- 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 %.

How Big A Temperature Effect?

- Smaller temperature increases (in the order of 2°C) have small overall effects, negative in some areas and and positive in others
- Larger temperature increases (on the order of 4°C) 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 °C 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 earlie seeding
- In the mid latitudes the increase in season lengths may be sufficient to allow the adoption 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

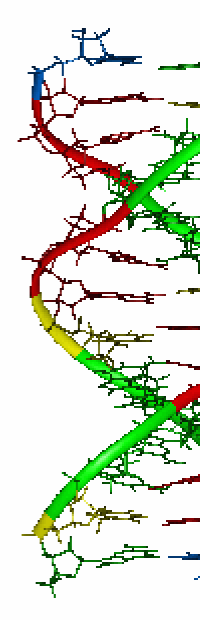
Pesticides

- 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 intensify

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

Genetic Potential - What’s out there

Craterostigma

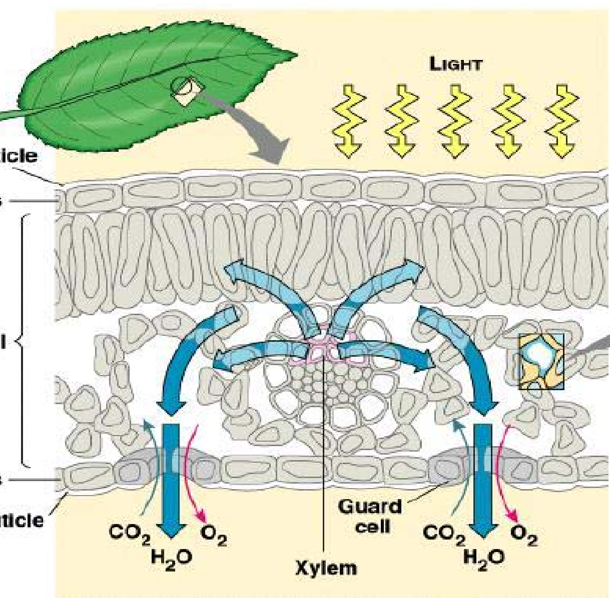
- Some plant tissues can survive extreme desiccation
  - pollen
  - seeds
  - spores

- Resurrection plants can dehydrate completely, and ther rehydrate quickly, with little damage
- Crop plants do not have this ability, but there is variability among and within crop plants f drought tolerance

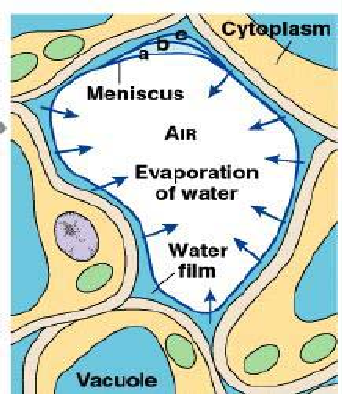
ater's Pathway

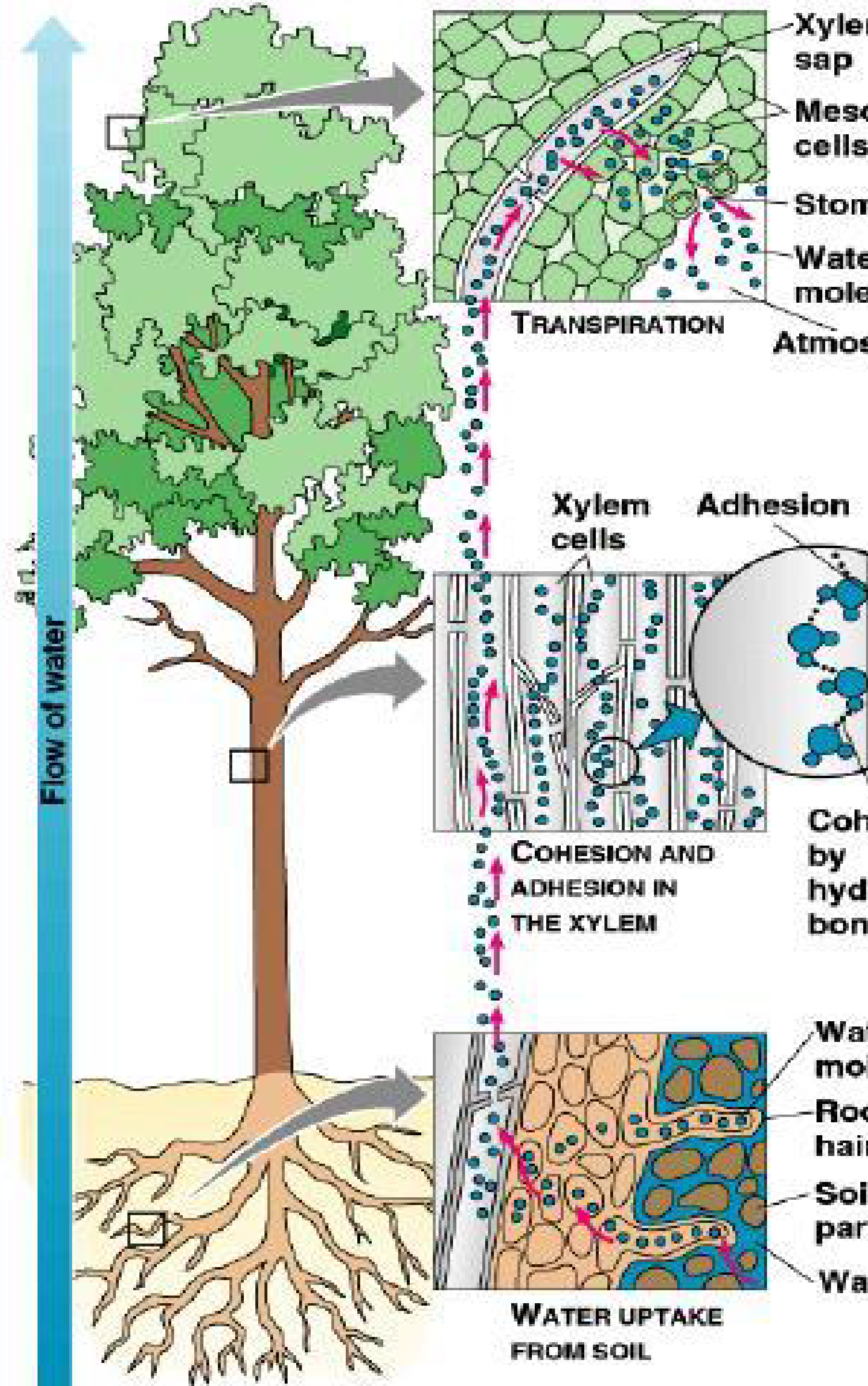
- 9%of water absorbed is ost by transpiration
- rop uses ~10,000 t ha^{-1} eason^{-1}
- lmost all aspects of plant nvolved so many genes

Transpiration



Radius of curvature (μm)	Hydrostatic pressure (MPa)
a = 1.00	a = −0.15
b = 0.10	b = −1.50
c = 0.01	c = −15.00

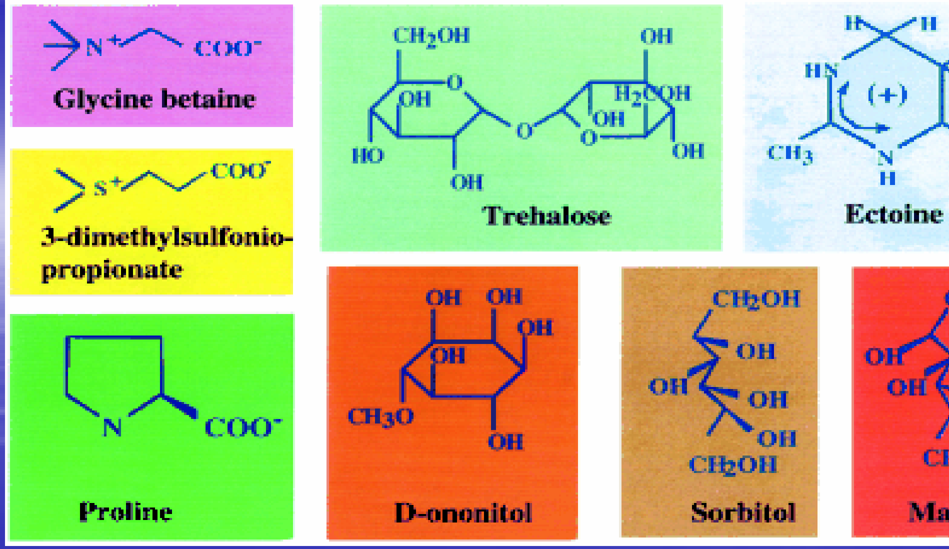




Roots

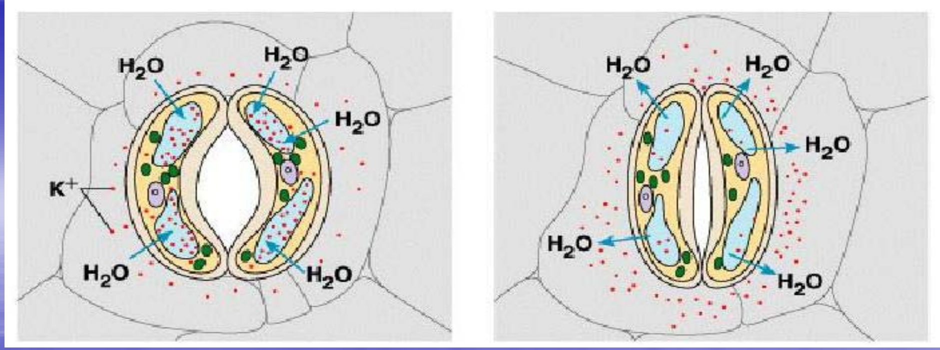
- Plants with at least longer roots are often more drought tolerant
- Roots able to penetrate soil better, particularly hard pans, help in this regard
- Longer roots allow the plants to extract water from deeper in the soil and therefore plants with such roots have more water to draw upon to complete growth and development

Osmotic Adjustment



- Less water in the soil
  - water potential in the xylem columns is less
- Other cells in the plants have a harder time coaxing water out of the xylem
- They produce higher concentrations of specific osmolites to decrease their water potential, and pull water from the xylem stream
- Plants that have a higher capacity for this are generally more drought tolerant

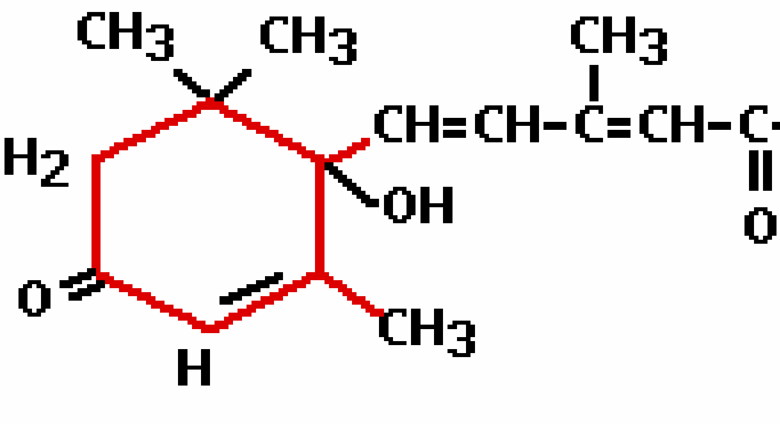
Stomatal Control



- Most water leaves the plants through the stomat
- Plants must have stomata to let CO_2 in, but wate escapes as a result
- Plants close their stomata in response to water stress, but this means less CO_2 fixation
- Some plants close stomata easily, others have them sunken in pits or surrounded by hairs
- Plants that are able to photosynthesize more rapidly with partially closed stomata are more drought tolerant

Roles of ABA

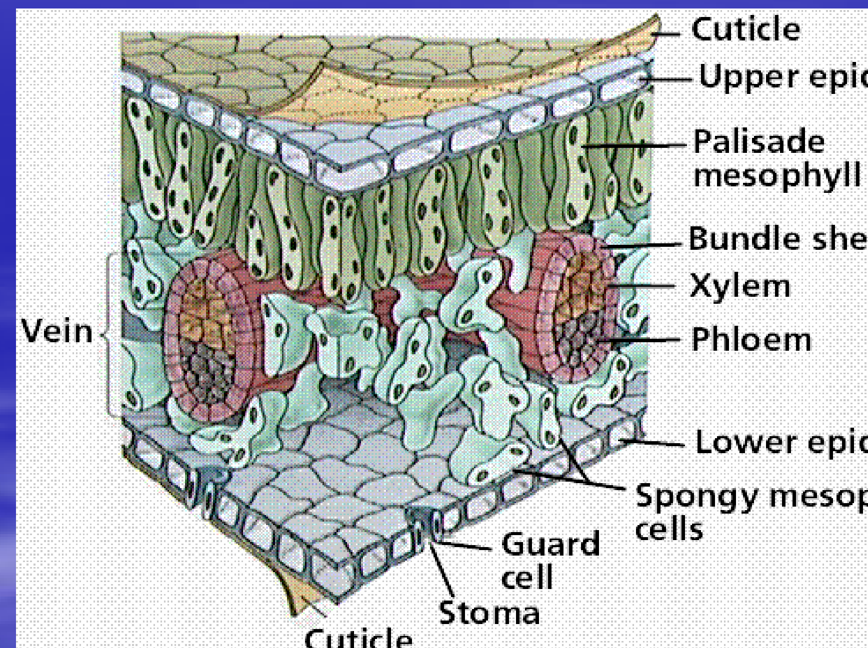
- Abscisic acid levels rise at the onset of drought stress
- Stomatal closure
  – ion channels in guard cells
- Root growth
- Dessication tolerance
- Leaf (and fruit) abscission
- Seed maturation and dormancy
- Bud dormancy



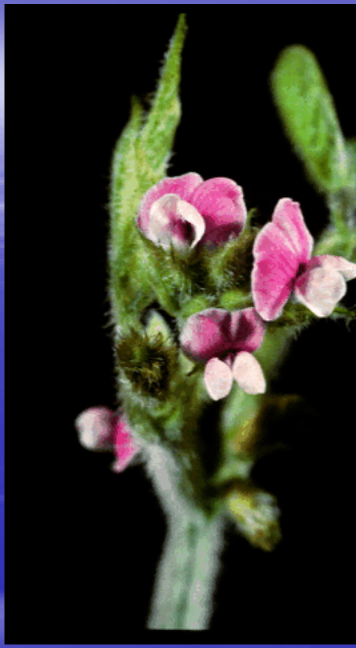
Abscisic acid (ABA)

Cuticular Transpiration

- Some water is also lost through the cuticle, a waxy relatively water impermeable coating on the leaf surface
- If this layer is thicker or made up of more water impermeable waxes and lipids the plants will loose less water
- Such plants are generally more drought tolerant



Changes in Development



- Stressed plants develop faster
  - flower sooner
  - senesce sooner
- With drought stress will develop smaller leaves
- May also shed (abscise) existing leaves
- Will produce fewer flowers and seeds and probably smaller seeds

Others

- Perihelionasty - change leaf orientation to minimize light interception
- Leaf rolling (grasses)
- Cuticle colour may reflect more light

Water Use Efficiency

- Amount of plant dry matter, or yield, produced per unit of water transpired
- Can be misleading, and a plant that conducts little photosynthesis may use little water, and may have good water use efficiency, but little yield
- We need plants with high water use efficiency and high productivity
- C_4 plants are generally better than C_3 plants

Overall

- Because so many aspects of plant development and metabolism are involved in plant-water relationships:
  - There is a lot of potential for genetic improvement
  - The situation is complex and it will take time

Climate change - Some Other

Policy

- Policies that promote the production of established crops in a given area must be made flexible to allow the introduction of new crops and cropping practices

Adaptation Inequities

- Developed countries in temperate zone areas will have more resources to aid in adaptation than developing countries
- Developing countries will also have greater negative effects to deal with

The End!

to by S. Wood