Biosourcing – Green chemistry 2014-2015

Plant Biology Course Syllabus

- Introduction to Plants
- Secondary Metabolites from Plants
- Plant Biotechnologies and Genetic Engineering
- Plants as Bioreactors
- Phytoremediation

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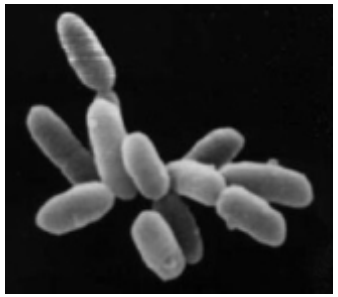
Why study plants?

Plants, like most animals, are multicellular eukaryotes



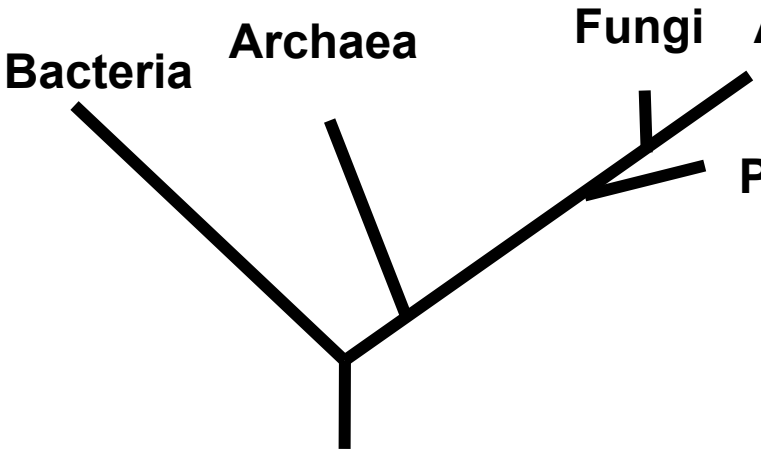
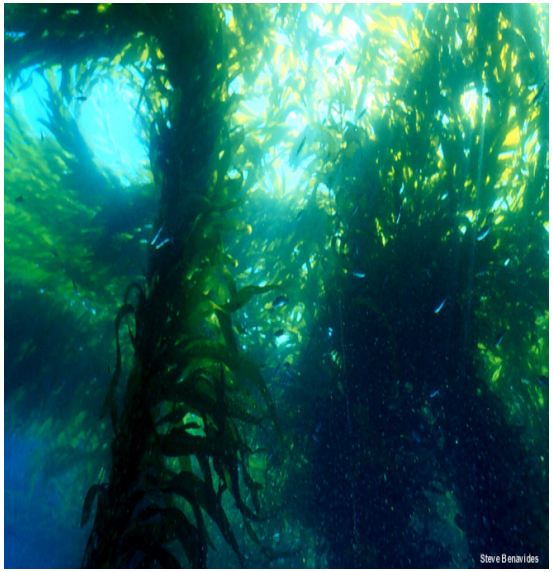


Photo credits: Public Health Image Library; NASA; © Dave Powell, USDA Forest Service; tom donald

The Plant Kingdom

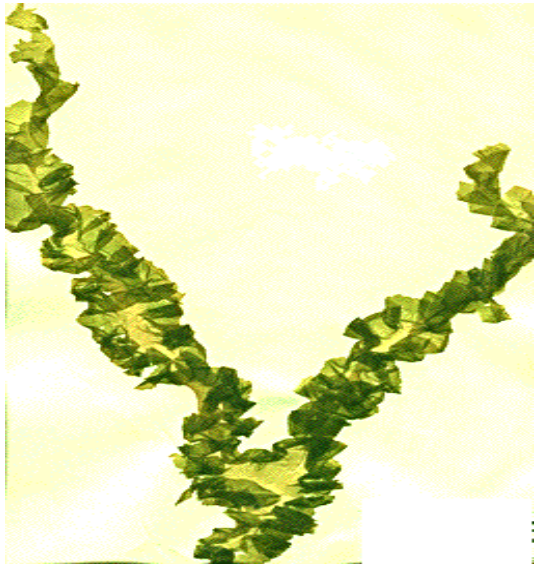
The oldest and most simple photosynthetic organisms on earth are algae.

The multicellular algae are separated into divisions based on their photosynthetic pigments, food storage products, and cell-wall components. The three major groups include:



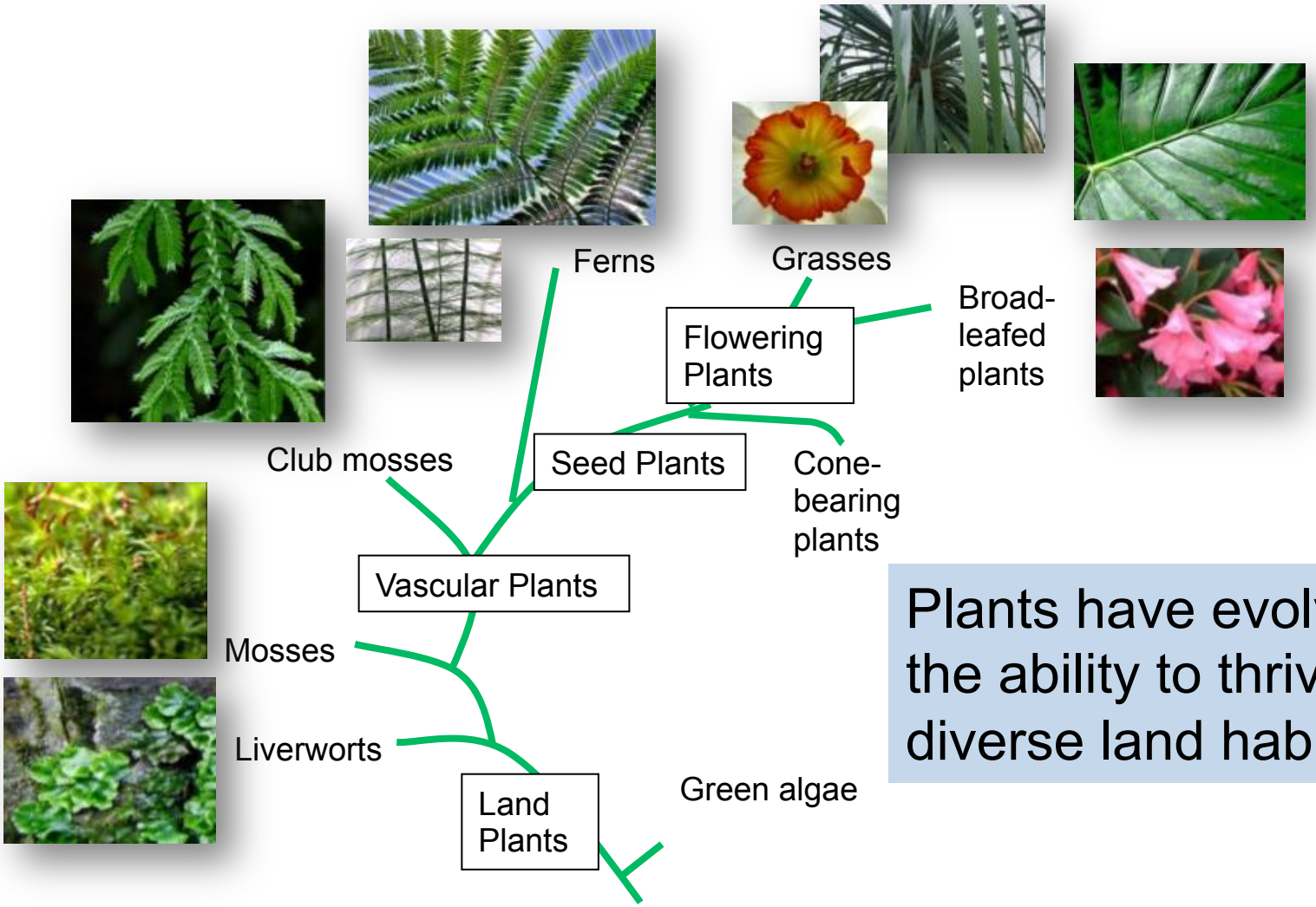
Brown algae

Red algae



Green algae

Plants are diverse

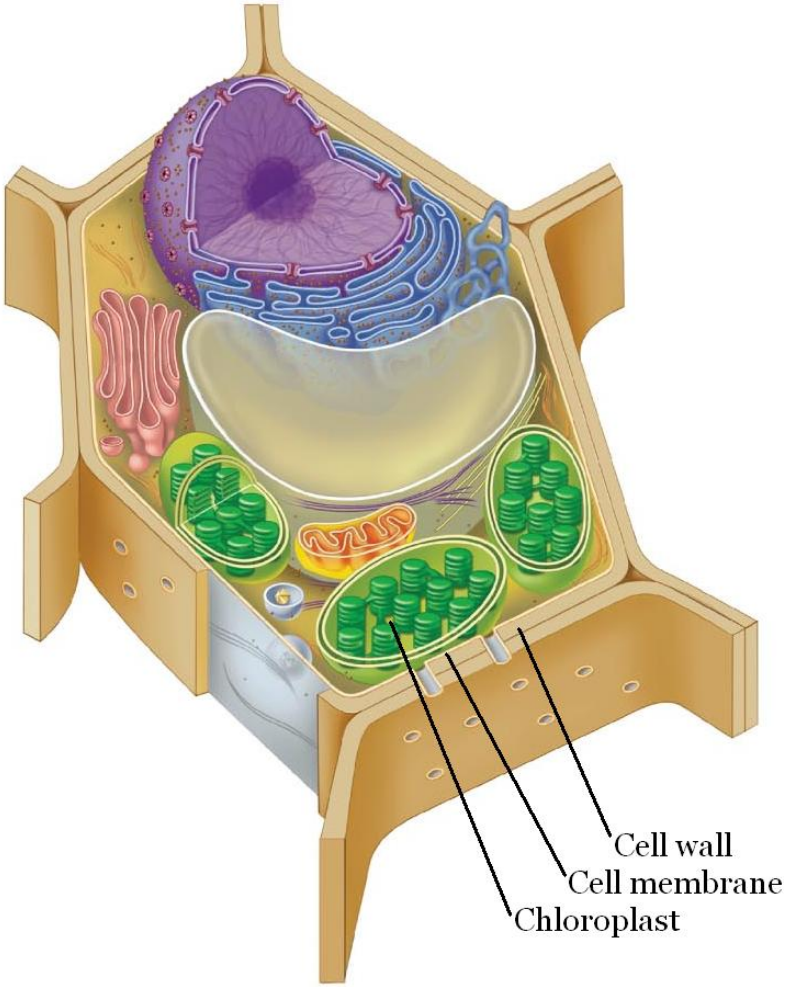


Plants have evolved the ability to thrive in diverse land habitats

Images courtesy tom donald

Plants are different

- Cell walls of cellulose
  - complex carbohydrate
- Acquire energy by photosynthesis
  - Chloroplasts with chlorophyll a, b
  - Chlorophyll reflects green part of visual spectrum

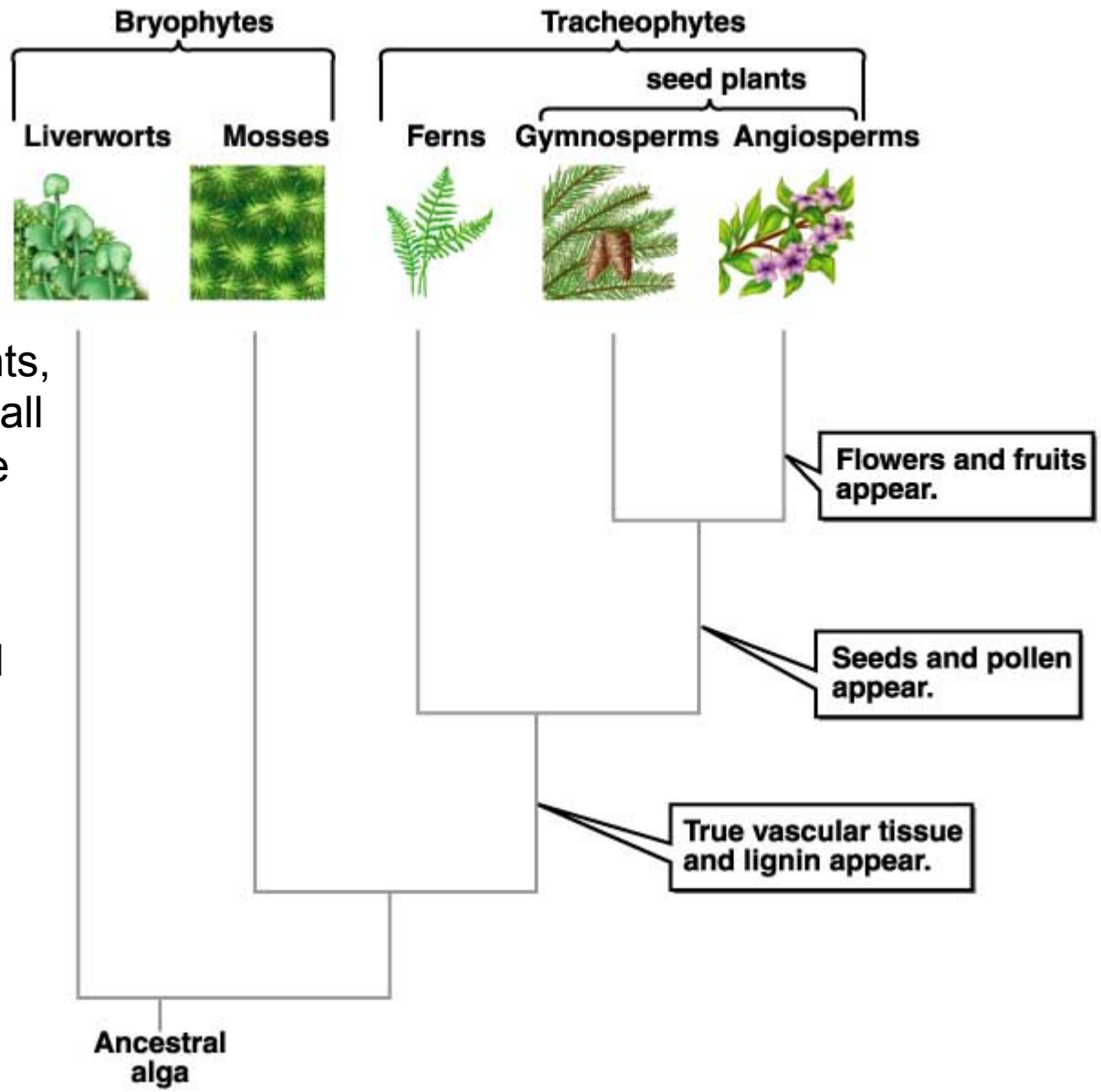


The Plant Kingdom

Green algae are thought to have given rise to the "higher" plants.

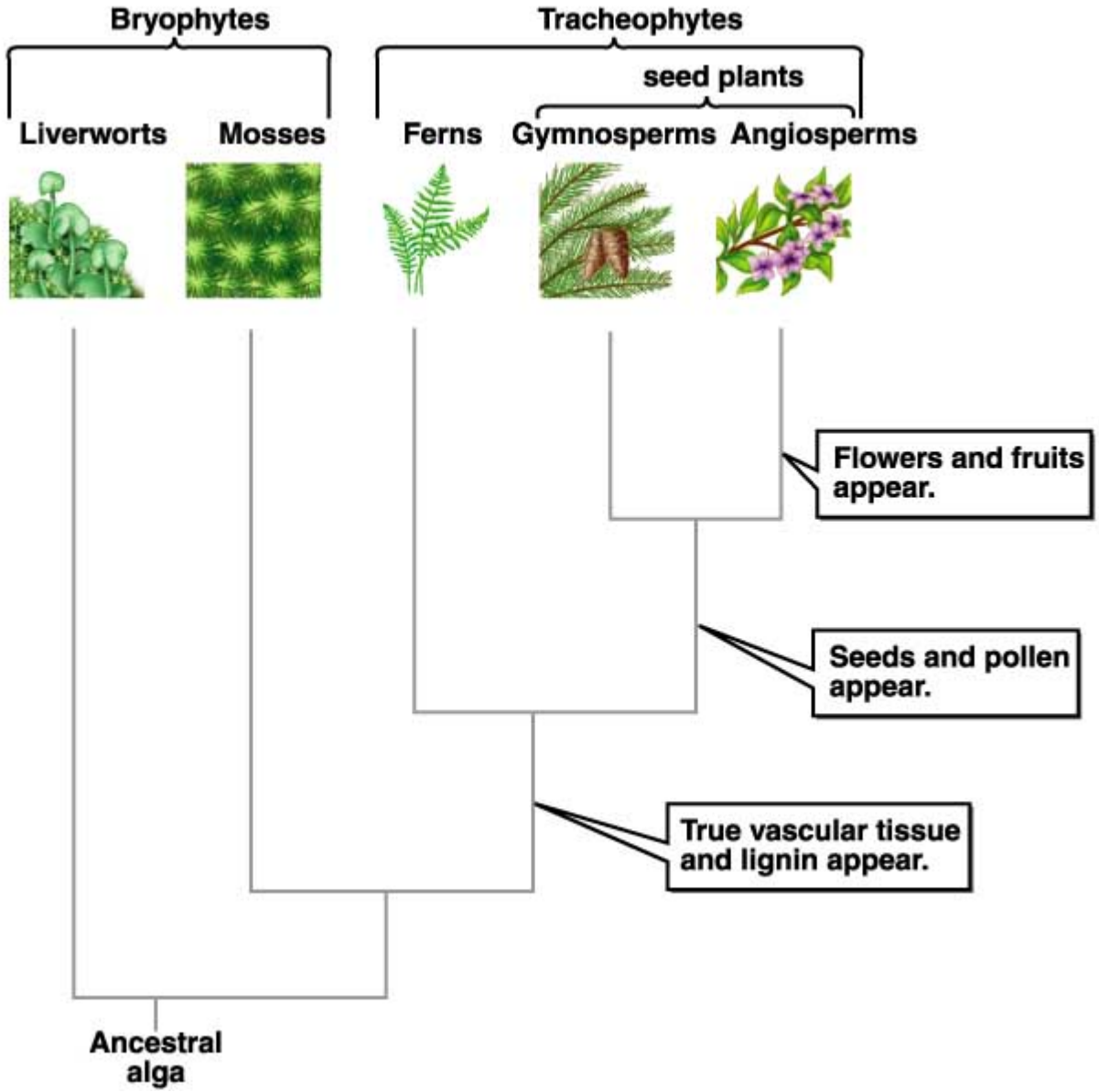
They have the same pigments, storage products, and cell-wall type. Also, many of them live in fresh water…

The different plants selected for adaptations that allowed them to exploit more of the terrestrial regions…



The Plant Kingdom

Although liverworts, mosses, and particularly ferns have many adaptations for life on land, gymnosperms and angiosperms are the only plants that are most adapted for life on land… hence their success!!!



Plants are amazing living organisms

Largest flower (~ 1m)

Longest living (~ 5000 years)

Largest organism (> 100m)

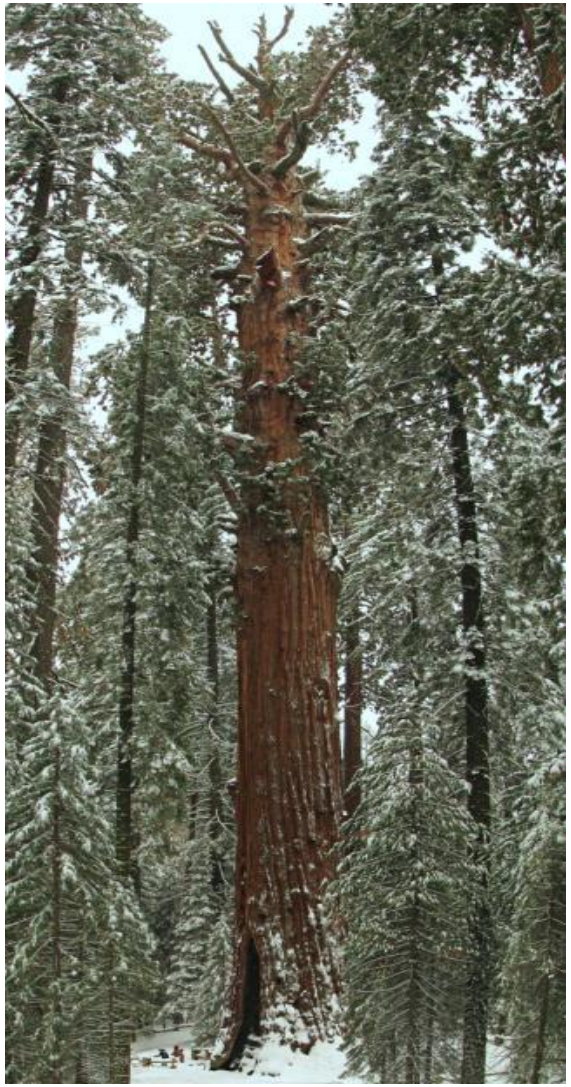


Photo credits: ma_suska; Bradluke22; Stan Shebs

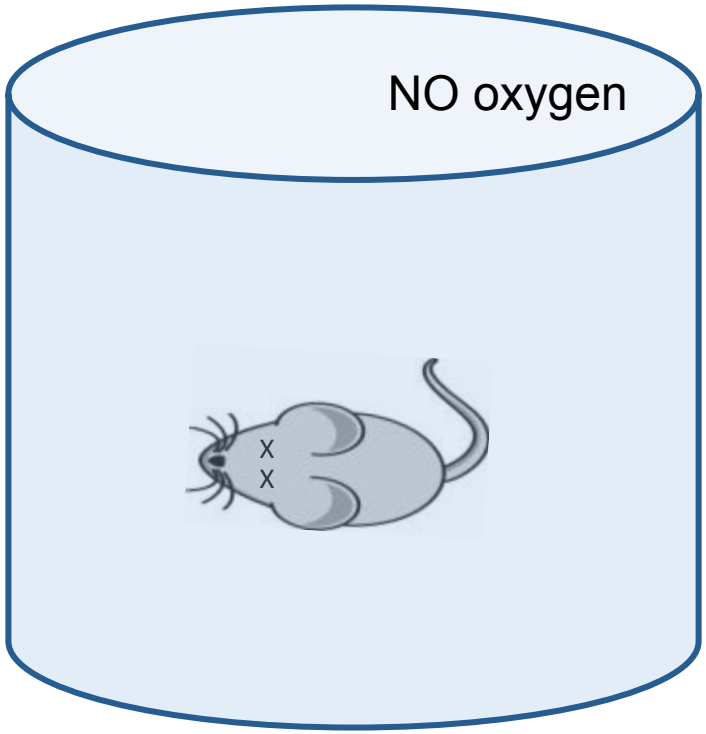
We could not live without plants

•Plants produce most of the oxygen we breathe.

•Plants produce most of the chemically stored energy we consume as food and burn for fuel.

•Plants produce an amazing assortment of useful chemicals.

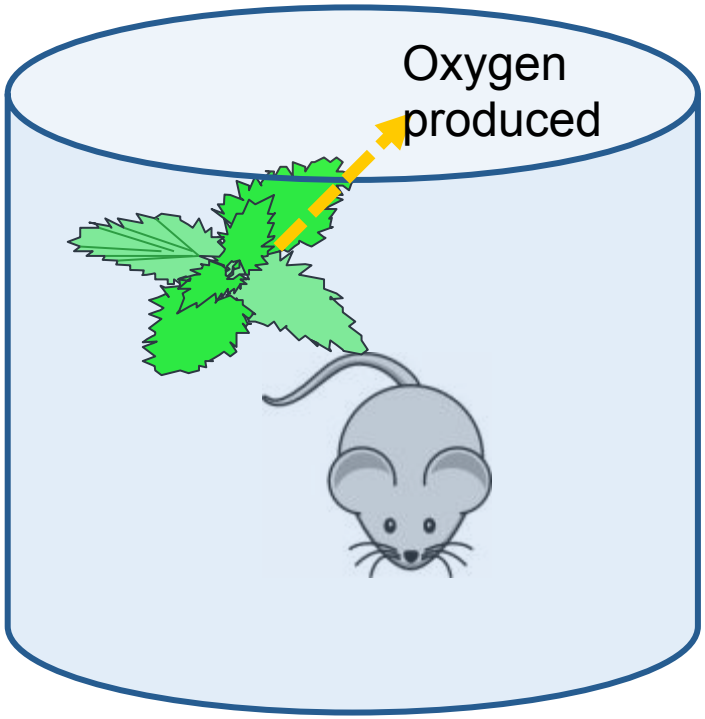
We can’t live without oxygen!



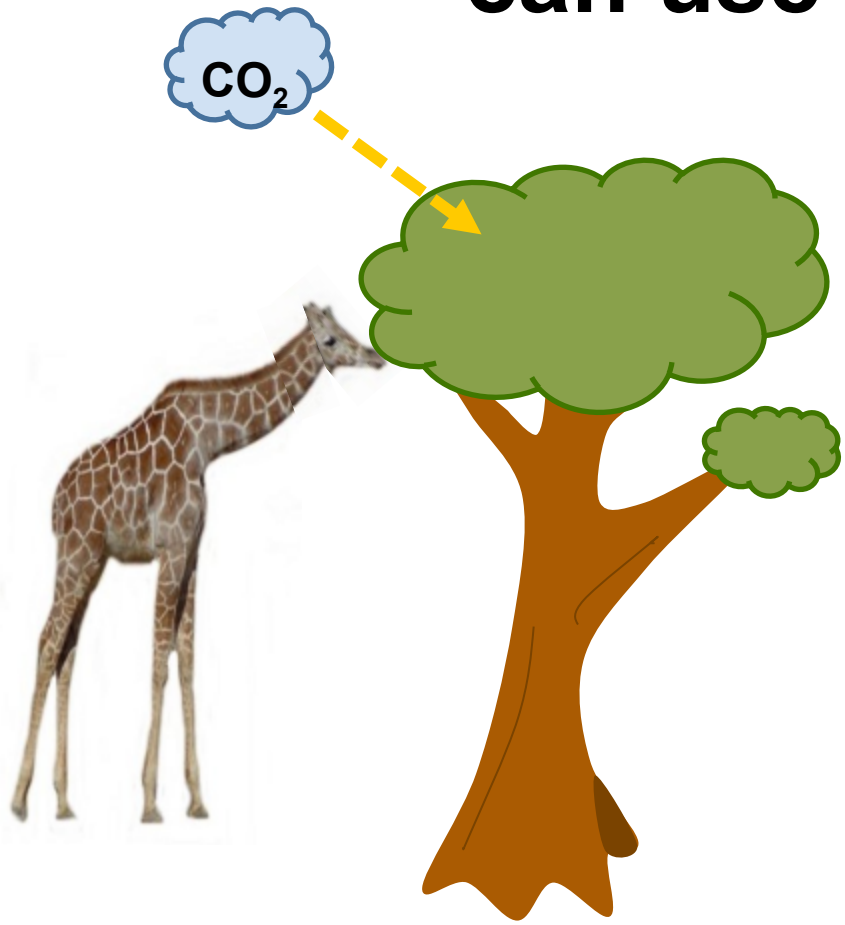
Joseph Priestley recognized that an animal’s breathing “injured” air. An animal kept in a sealed container would eventually pass out.

We can’t live without oxygen!

Priestley also recognized that plants have the ability to “restore” the air. We now know that they produce oxygen as a by-product of photosynthesis.



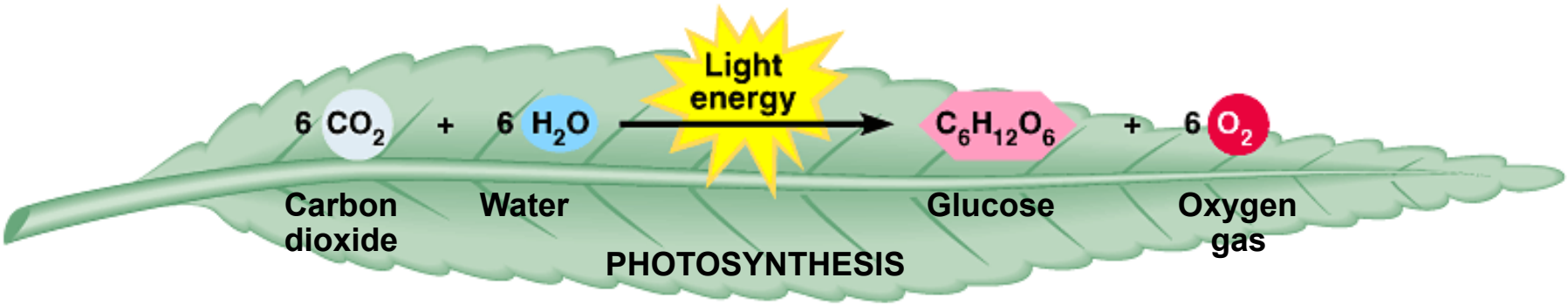
Plants fix carbon dioxide into energy- rich molecules we animals can use as food



Plants convert CO_2 gas into sugars through the process of **photosynthesis**.

AN OVERVIEW OF PHOTOSYNTHESIS

Photosynthesis is the process by which autotrophic organisms use light energy to make sugar and oxygen gas from carbon dioxide and water

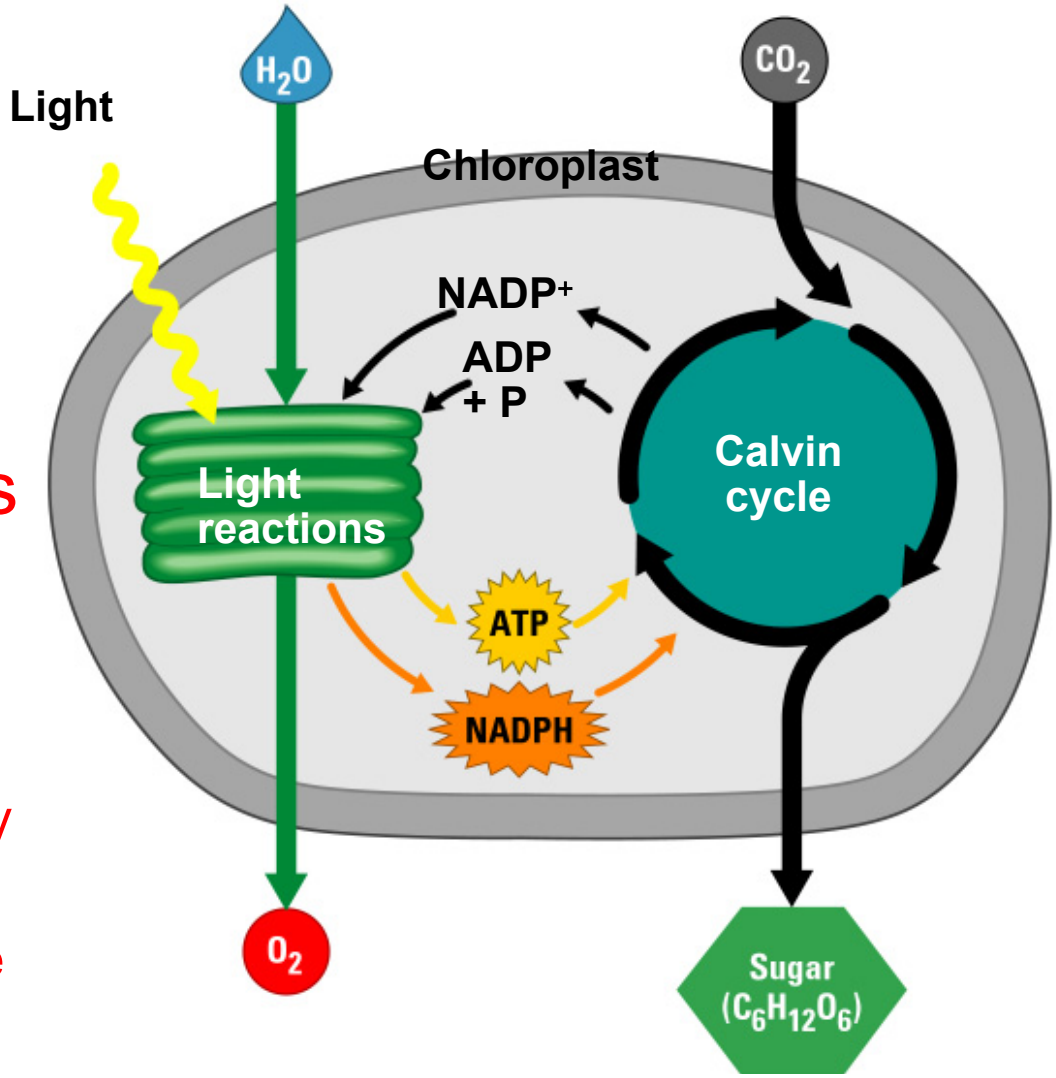


AN OVERVIEW OF PHOTOSYNTHESIS

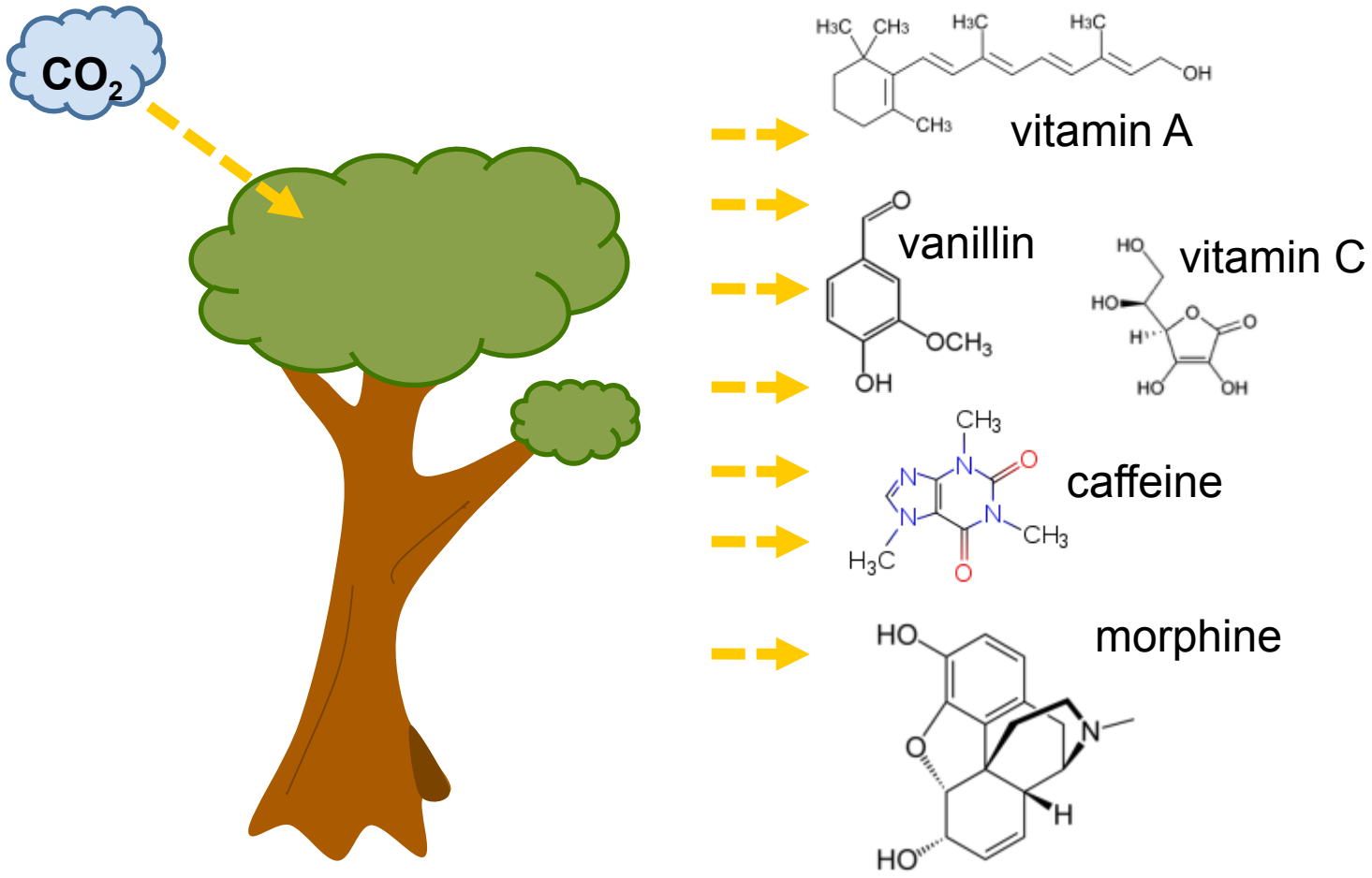
The light reactions convert solar energy to chemical energy

- Produce ATP & NADPH

- The Calvin cycle makes sugar from carbon dioxide
  - ATP generated by the light reactions provides the energy for sugar synthesis
  - The NADPH produced by the light reactions provides the electrons for the reduction of carbon dioxide to glucose

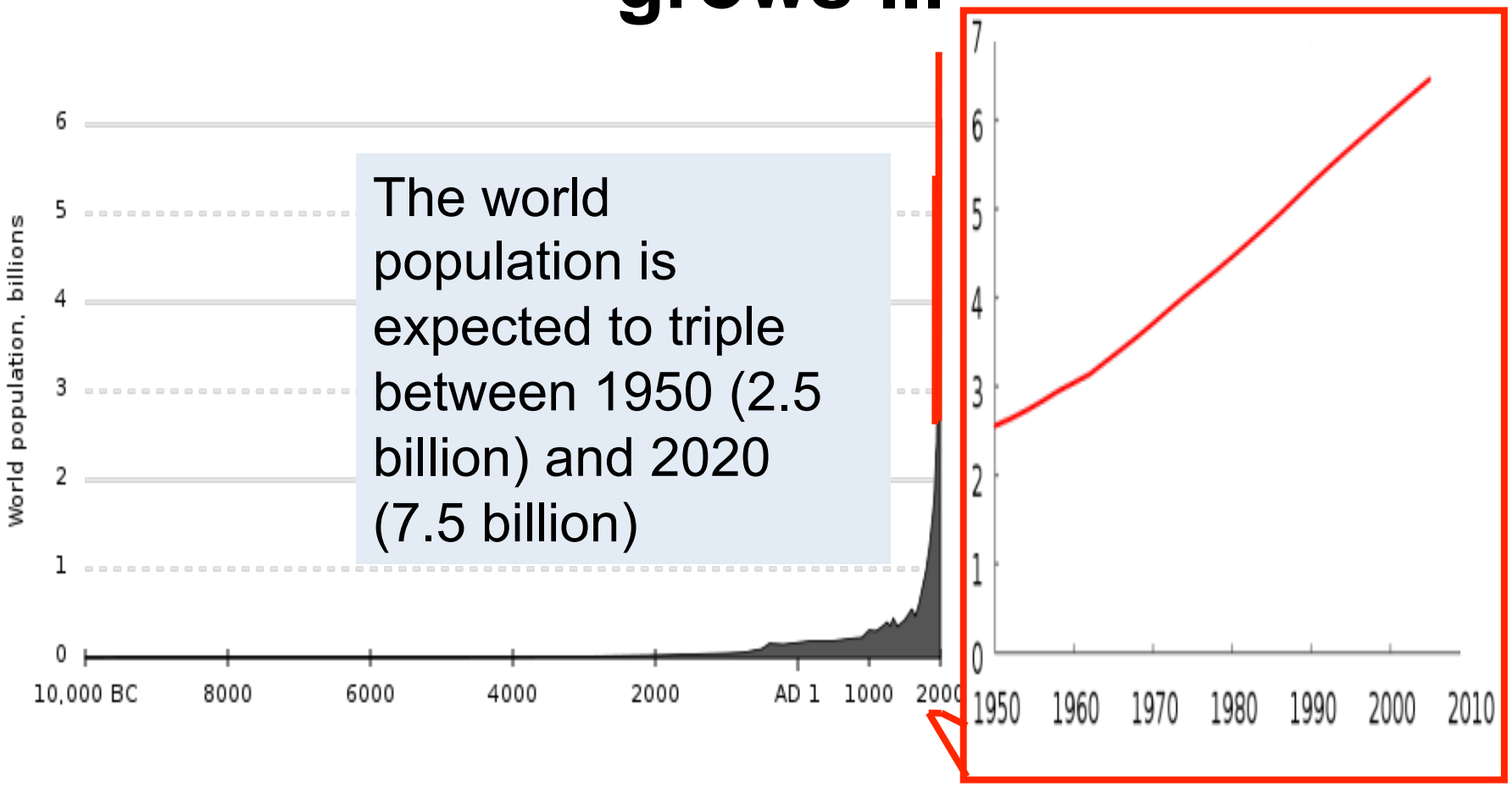


Plants can produce an amazing assortment of chemicals



WHY STUDY PLANTS?

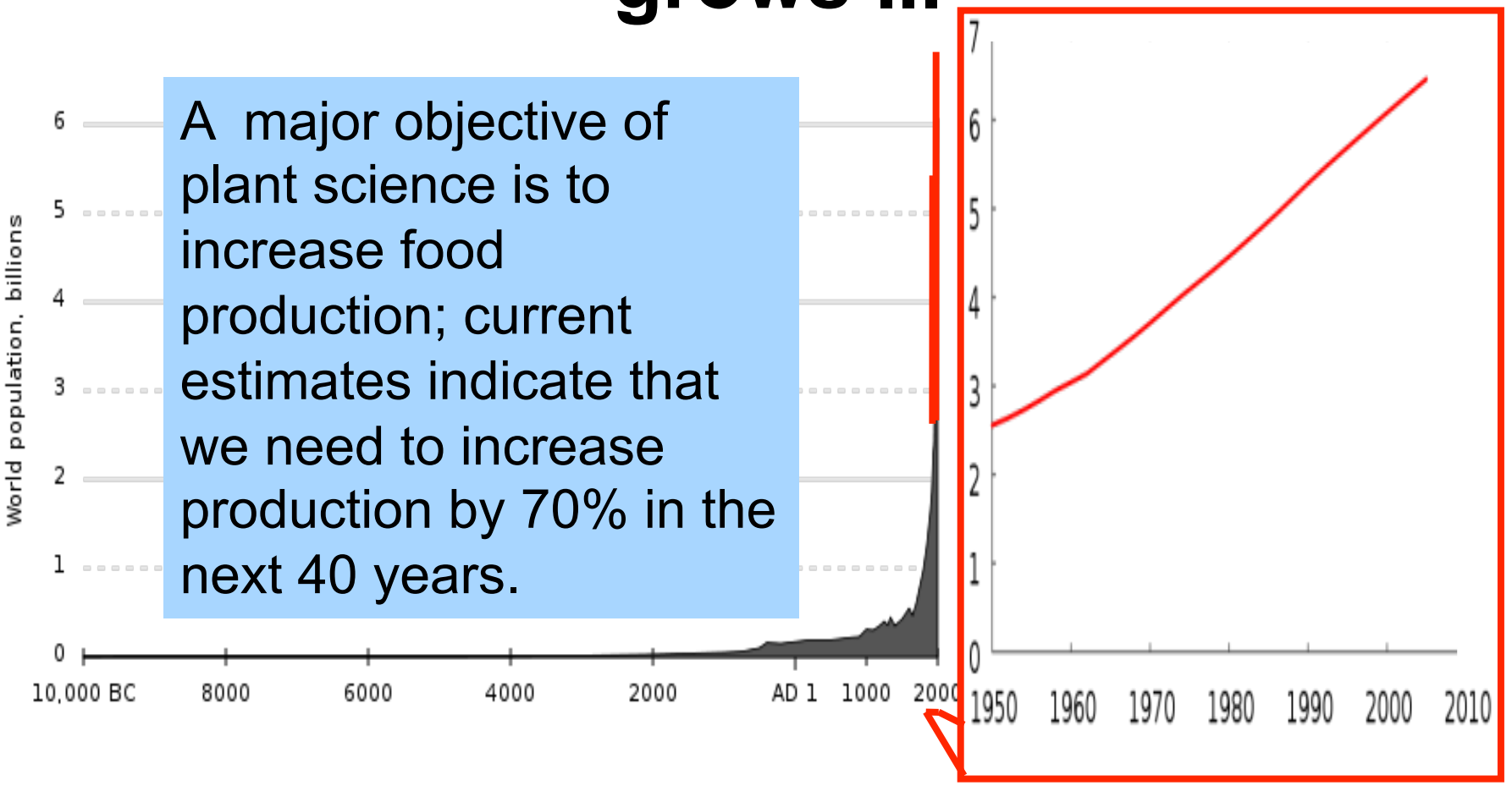
The world population grows and grows ...



The world population is expected to triple between 1950 (2.5 billion) and 2020 (7.5 billion)

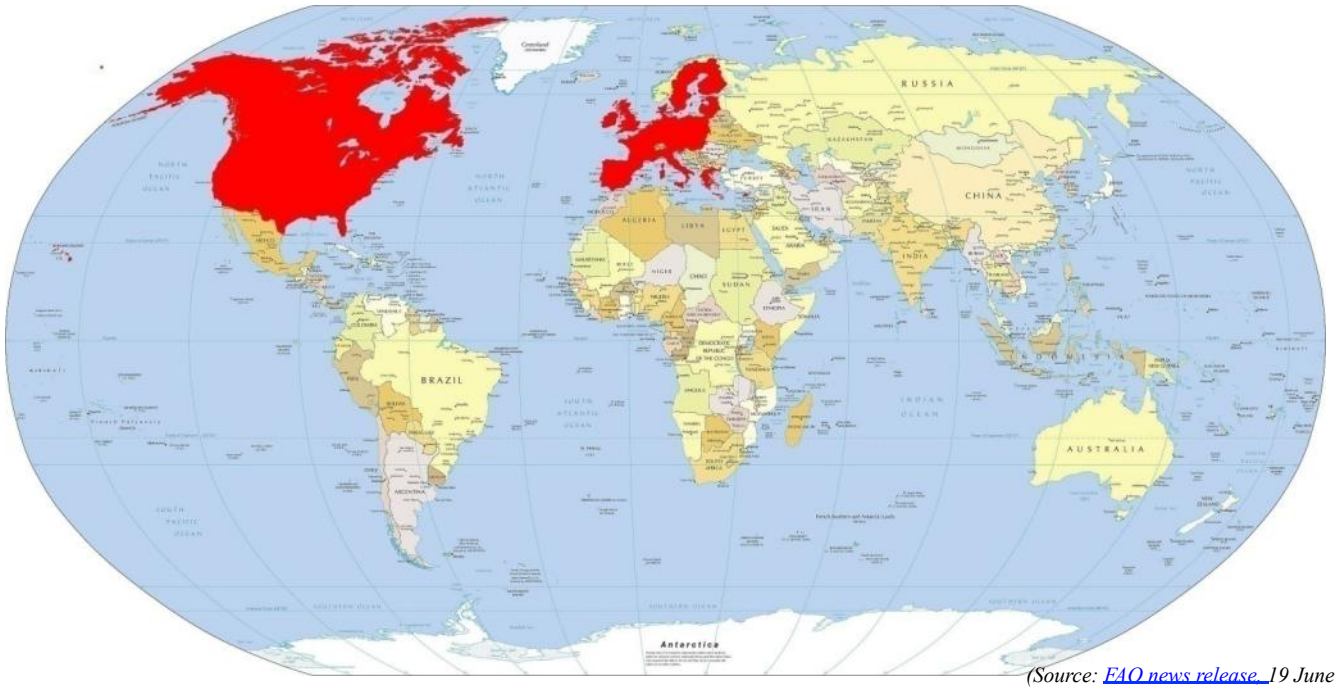
The world population grows and grows ...

A major objective of plant science is to increase food production; current estimates indicate that we need to increase production by 70% in the next 40 years.



Globally, more than one billion people per year are chronically hungry

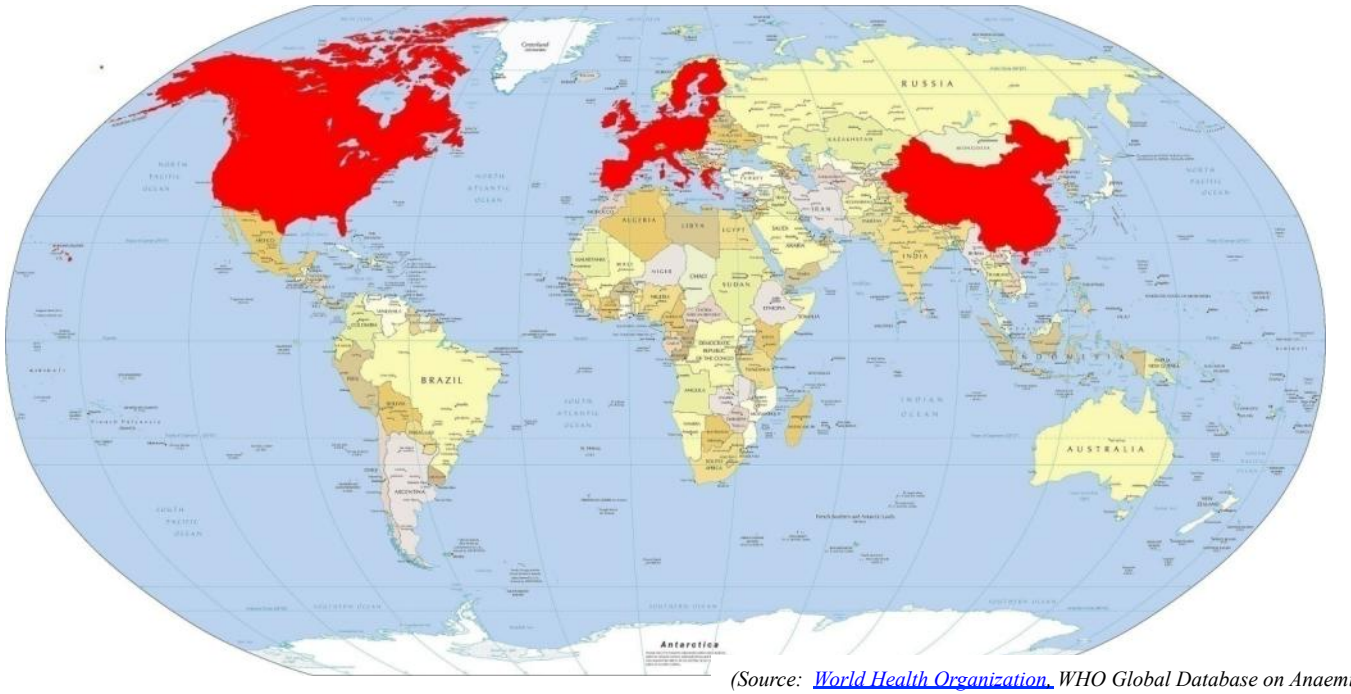
That's *more* than the total population of the USA, Canada and the EU.



(Source: FAO news release, 19 June 2009)

More than *two* billion people per year are chronically anemic due to iron deficiency

That's about the total population of the USA, Canada, the EU, and China.



(Source: World Health Organization, WHO Global Database on Anaemia)

WHAT CAN SCIENTISTS DO ABOUT THIS?

Plant scientists can contribute to the alleviation of hunger

By developing plants that

- are drought or stress tolerant
- require less fertilizer or water
- are resistant to pathogens
- are more nutritious

Plant growth is often limited by drought stress

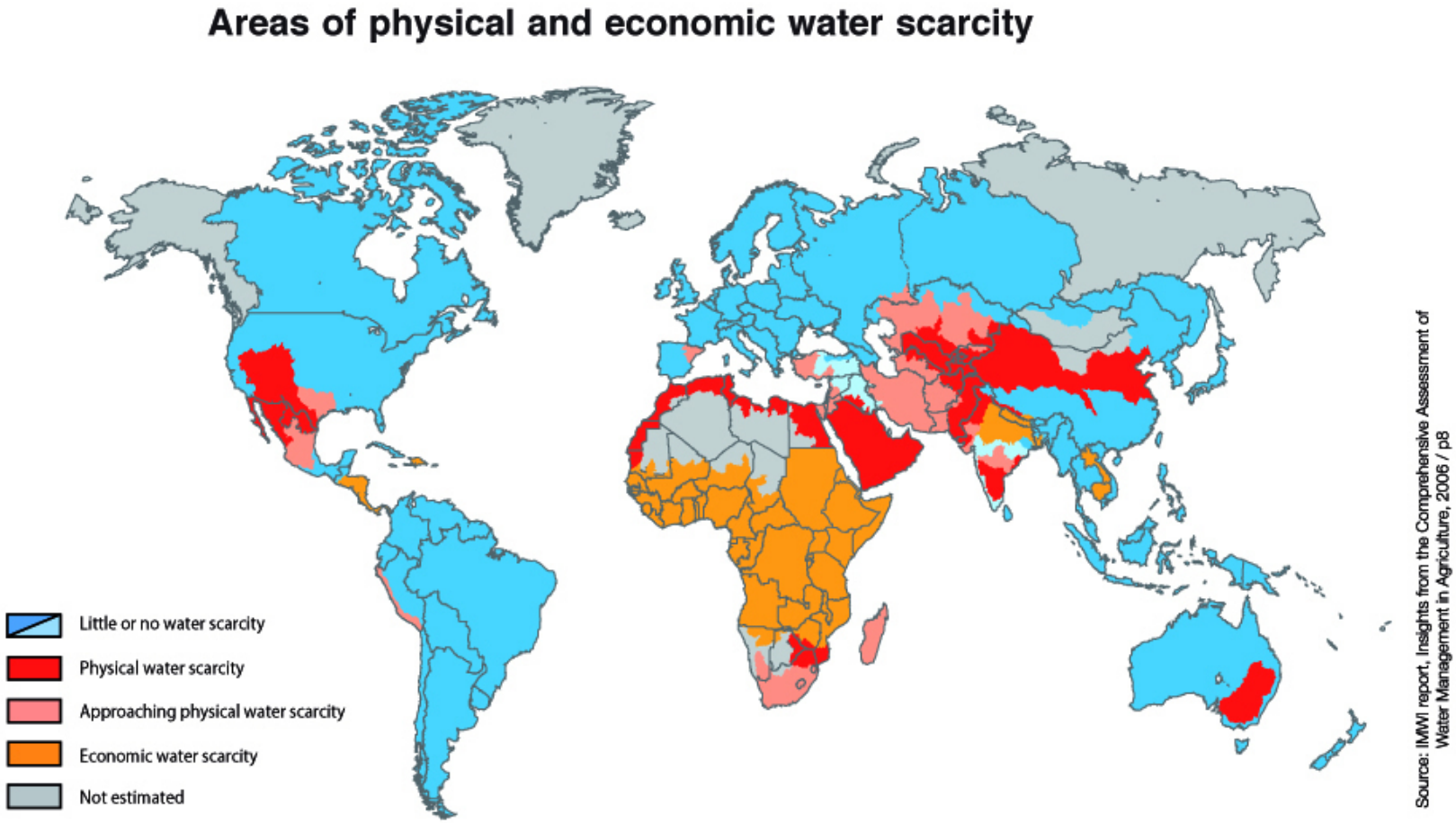
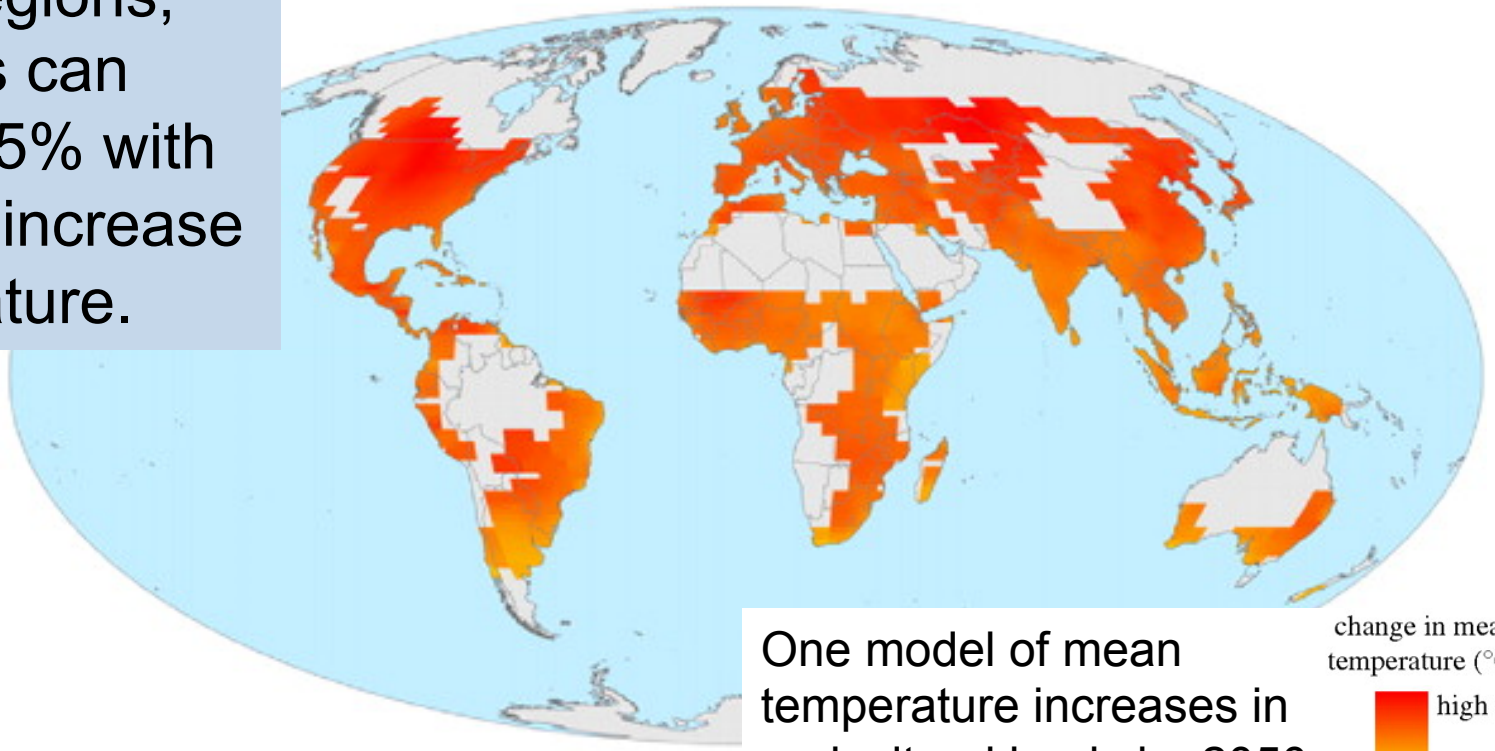


Image source: IWMI

Drought stress is compounded by increasing global temperatures

In warm regions, crop yields can drop ~3 – 5% with every 1°C increase in temperature.



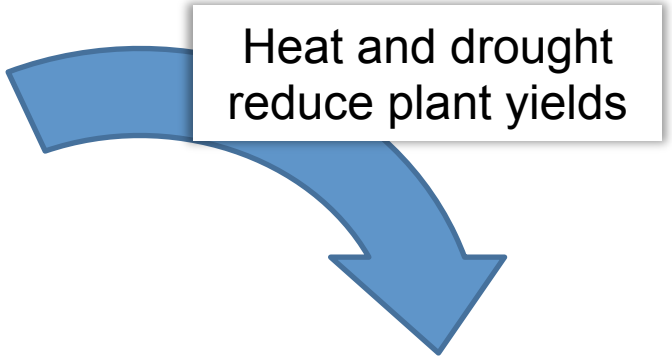
One model of mean temperature increases in agricultural lands by 2050.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., and Wiltshire, A. Implications of climate change for agricultural productivity in the early twenty-first century. Phil. Trans. Royal Soc. B: 365: 2973-2989.m

Even mild drought stress reduces yields

Mild drought stress reduces the rate of photosynthesis and growth, whereas extreme drought stress is lethal.

We need plants that grow well even under stressful conditions



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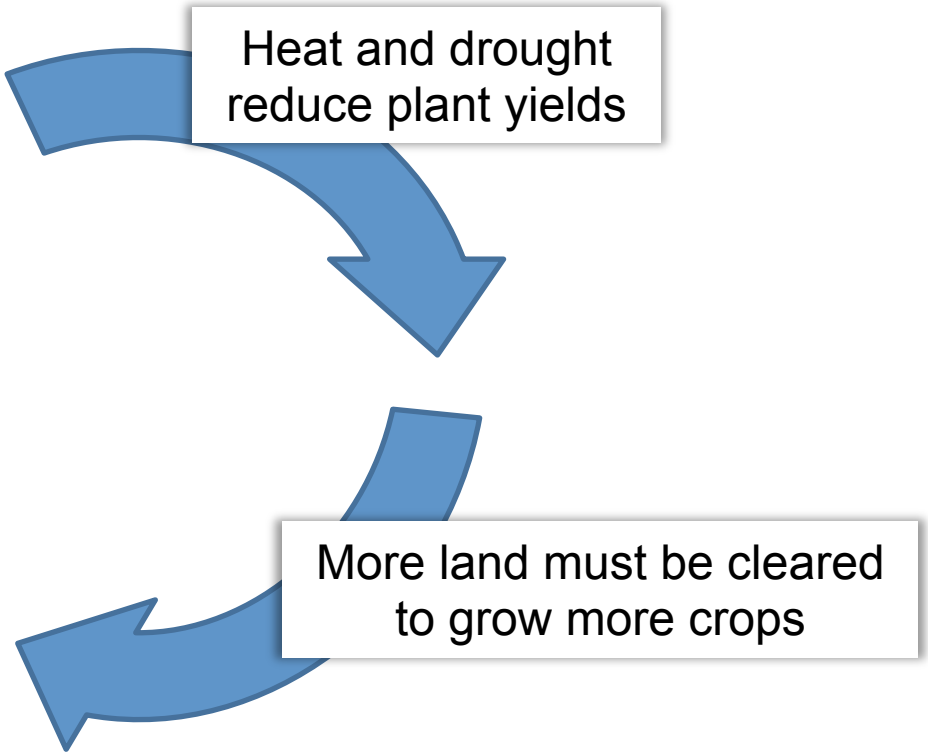

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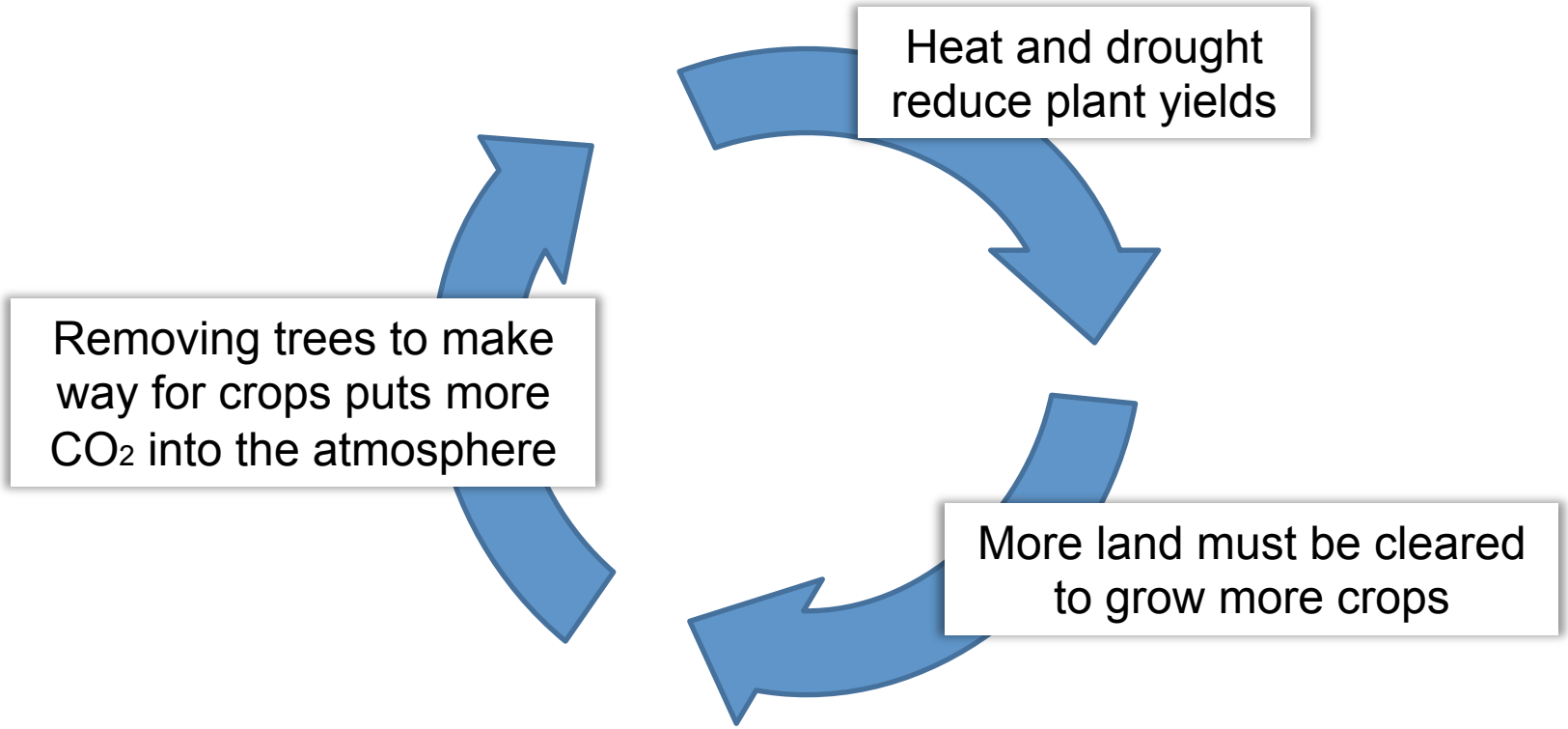
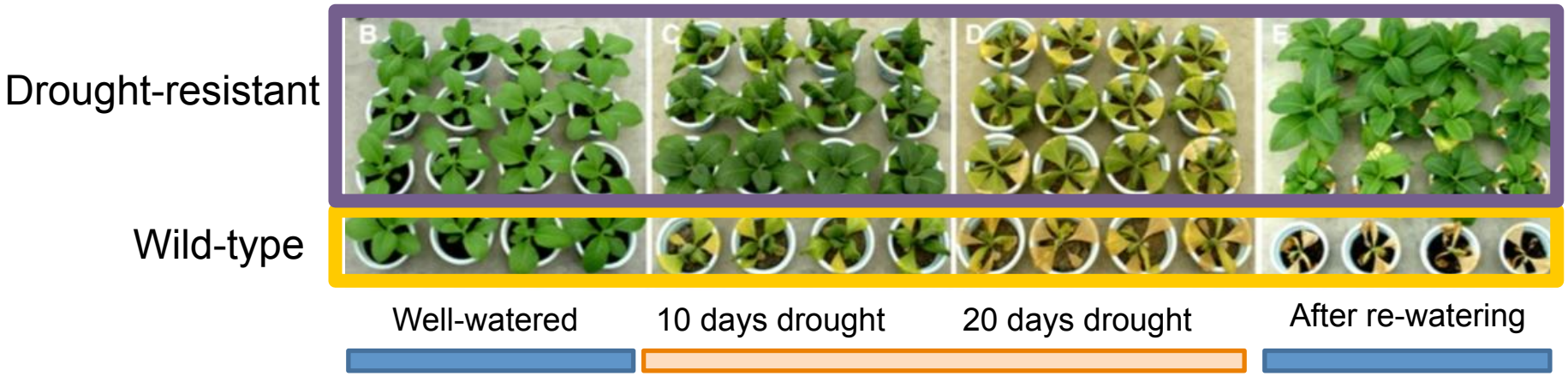
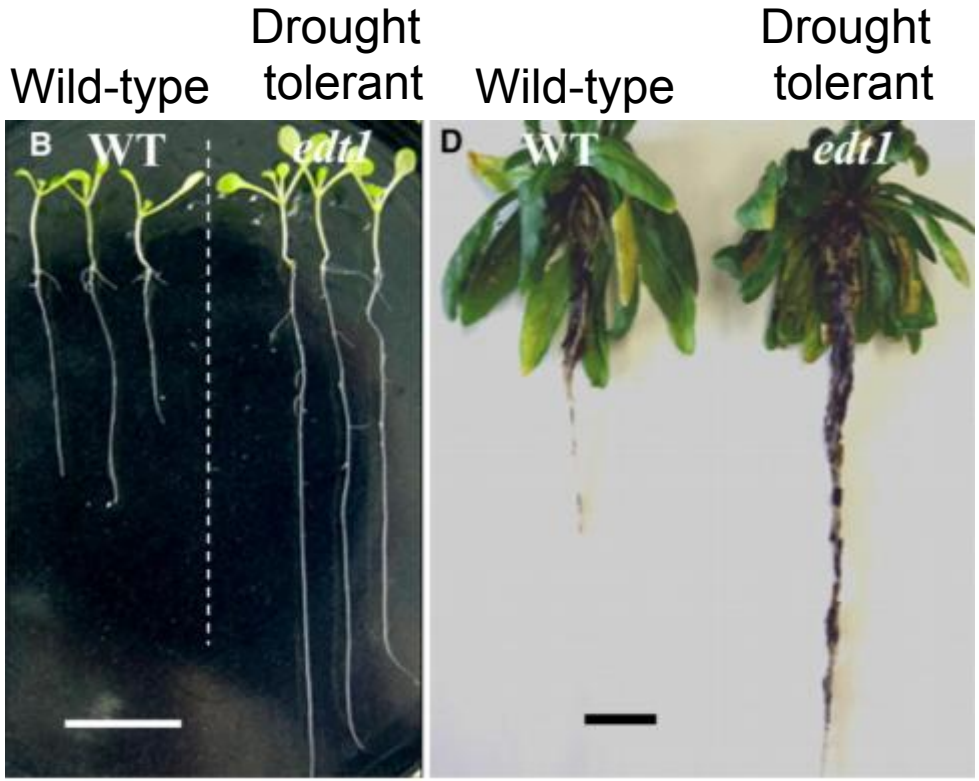


Altering a single gene can increase plants' drought tolerance



Yu, H., Chen, X., Hong, Y.-Y., Wang, Y., Xu, P., Ke, S.-D., Liu, H.-Y., Zhu, J.-K., Oliver, D.J., Xiang, C.-B. (2008) Activated expression of an *Arabidopsis* HD-START protein confers drought tolerance with improved root system and reduced stomatal density. Plant Cell 20:1134-1151.

A larger root system contributes to drought tolerance



Breeding plants for larger root systems can help them grow in drought-prone regions.

Yu, H., Chen, X., Hong, Y.-Y., Wang, Y., Xu, P., Ke, S.-D., Liu, H.-Y., Zhu, J.-K., Oliver, D.J., Xiang, C.-B. (2008) Activated expression of an *Arabidopsis* HD-START protein confers drought tolerance with improved root system and reduced stomatal density. Plant Cell 20:1134-1151.

Fertilizer is an energy-demanding limiting resource

- Crops need fertilizer – potassium, phosphate, nitrogen, and other nutrients

- Potassium and phosphate are non-renewable, mined resources

- Synthesis of nitrogen fertilizers requires huge amounts of energy

Photo credits: Mining Top News; Library of Congress, Prints & Photographs Division, FSA-OWI Collection, LC-USW361-374

Agricultural fertilizer use is a considerable source of environmental pollution

Fertilizer run-off causes dead zones, algal blooms that then decay, reducing oxygen levels in the water and making animal life impossible

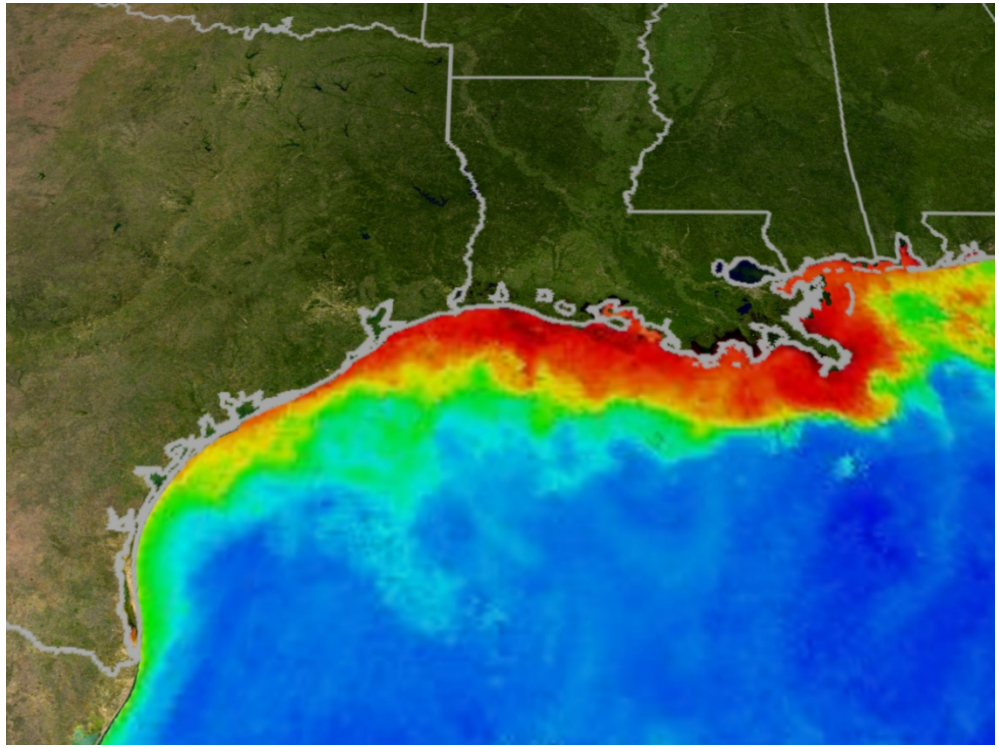


Photo courtesy of NASA/Goddard Space Flight Center Scientific Visualization Studio

Perennial plants uptake water and nutrients better than most crop plants

Scientists are crossing crop plants with perennial plants to reduce crop plants' dependency on fertilizers and water

Wes Jackson of the Land Institute holding a perennial wheat relative *Thinopyrum intermedium*

Photo credit: Jodi Torpey, westerngardeners.com

Right now, two serious diseases threaten the world's food supply

Phytophthora infestans, cause of potato late blight, has re-emerged as a threat.

Puccinia graminis tritici, the wheat stem rust fungus, has developed into a highly aggressive form.

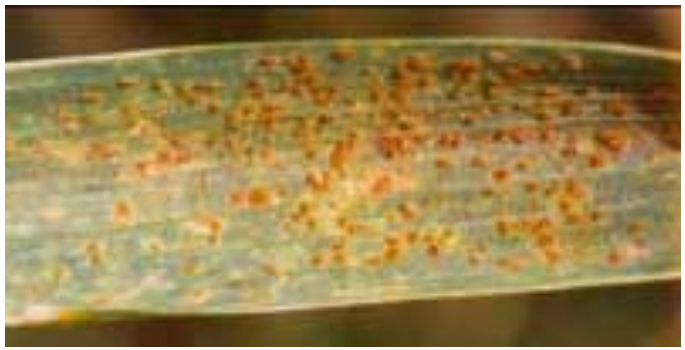
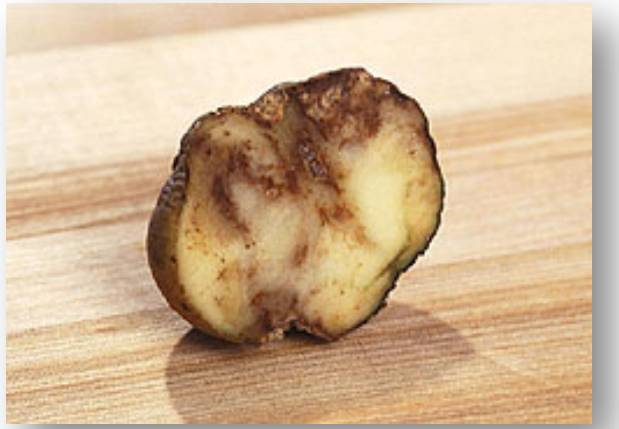


Photo credits: www.news.cornell.edu; www.fao.org

Late blight destroys potato plants



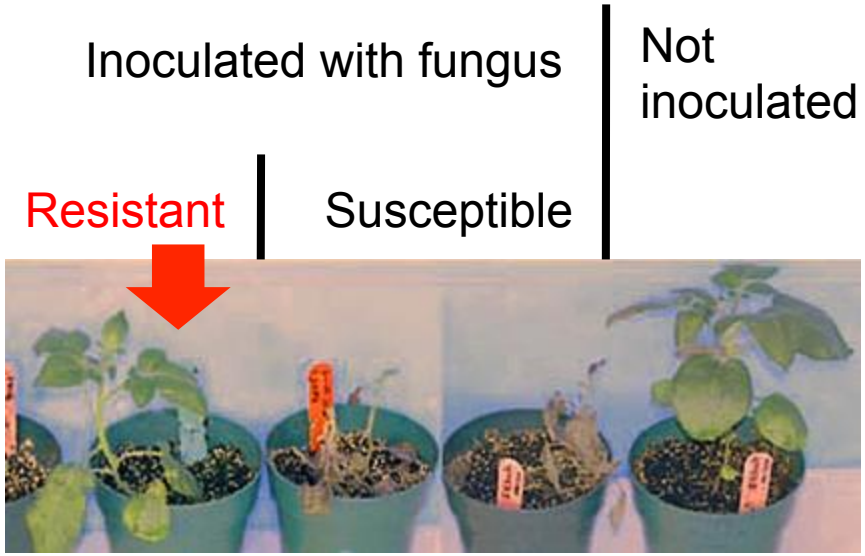
Potato late blight disease is caused by *Phytophthora infestans.* Outbreaks in the 1840s ruined crops and contributed to more than a million deaths in Europe.

Infected Treated

Photo credits: USDA; Scott Bauer

Identification of resistance genes

Geneticists have identified the gene conferring resistance and are introducing it into edible varieties.



The plant on the left carries the resistance gene and is free from disease symptoms.

Song, J., Bradeen, J.M., Naess, S.K., Raasch, J.A., Wielgus, S.M., Haberlach, G.T., Liu, J., Kuang, H., Austin-Phillips, S., Buell, C.R., Helgeson, J.P., Jiang, J. (2003) Gene *RB* cloned from *Solanum bulbocastanum* confers broad spectrum resistance to potato late blight. Proc. Natl. Acad. Sci. USA 100:9128–9133.

Wheat stem rust is an emerging threat

- A new, highly pathogenic strain emerged in Uganda in 1999 – it is called Ug99.
- Most wheat has no resistance to this strain.

Infected wheat plant

Photo credit: ARS USDA

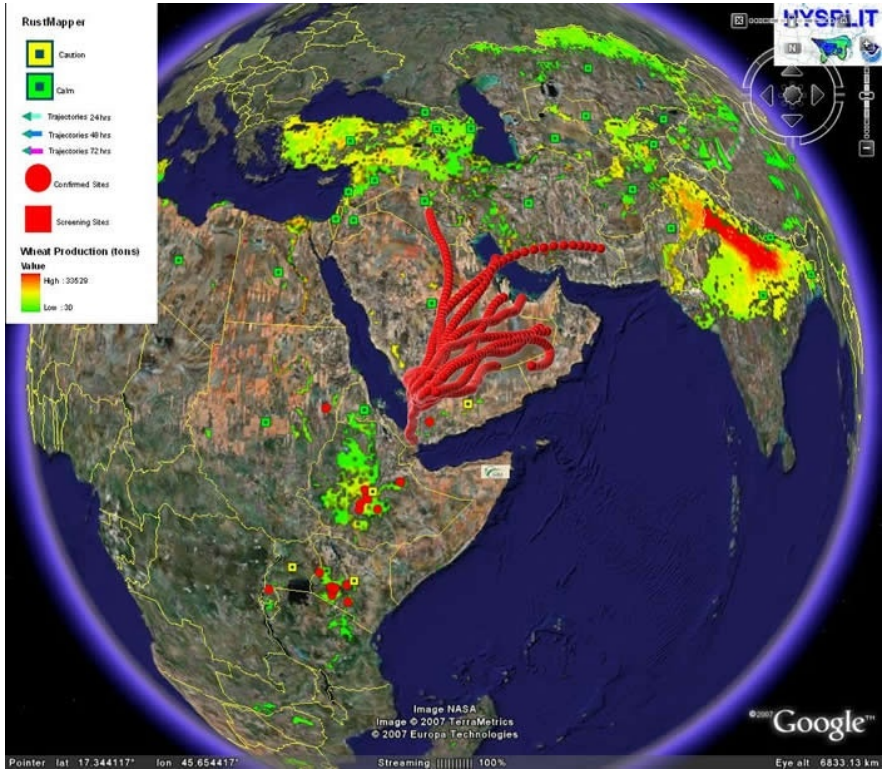
Ug99 threatens wheat everywhere

This is a global problem that needs global attention. Ug99 spores do not stop at national borders...

– *United Nations Food and Agriculture Organization (FAO)*

Photo credit: ARS USDA

The fungus is carried by wind

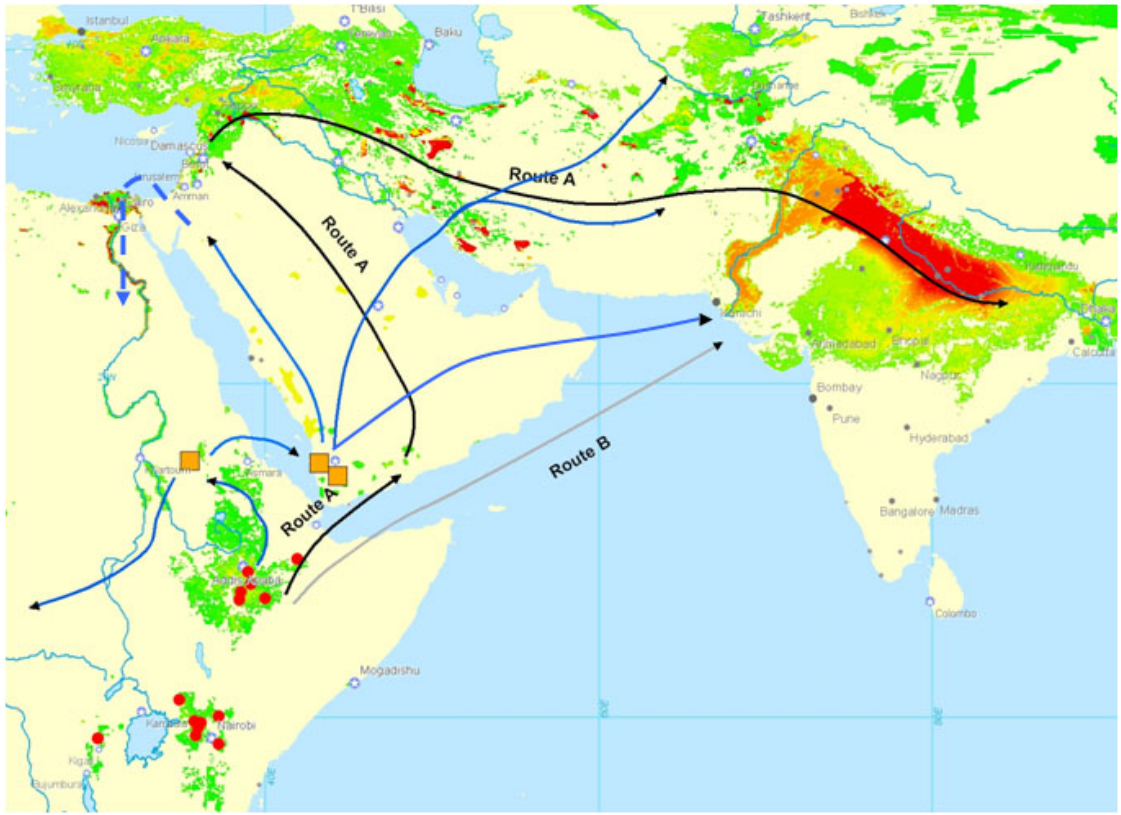


Ug99 is found in Uganda, Kenya, Ethiopia, Sudan, Yemen, and Iran, and threatens regions of the near east, eastern Africa, and central and southern Asia.

Wind currents carrying spores are shown in red.

Photo credit: www.wheatrust.cornell.edu

The fungus is carried by wind



Probable Ug99 trajectories

Wheat is the major food crop in many of these threatened regions, especially for the poorest inhabitants.

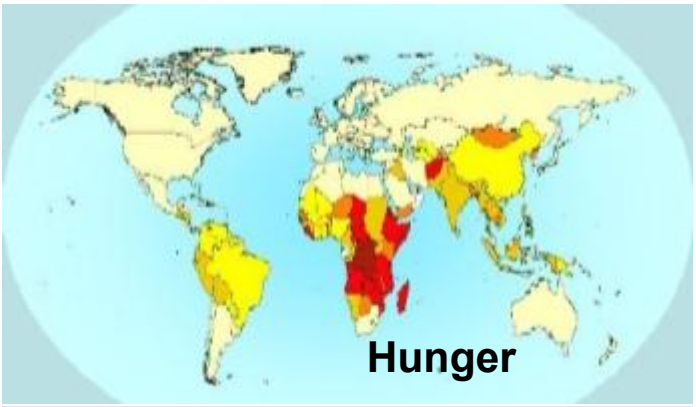
Photo credit: www.wheatrust.cornell.edu

International teams of scientists are cooperating to monitor the spread of Ug99 and develop wheat strains that resist it.

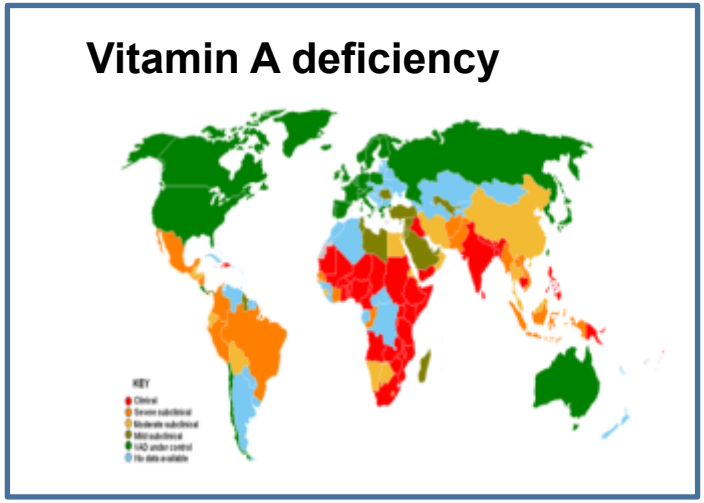
At this time, no one knows if resistant strains will be developed in time to avoid a major famine...

Photo credits: Bluemoose; FAO

Improved nutrient content in plants can help alleviate malnutrition



Subsistence level diets are usually nutrient-poor. Our bodies need vitamins and minerals as well as calories. Malnutrition is primarily a disease of poverty.



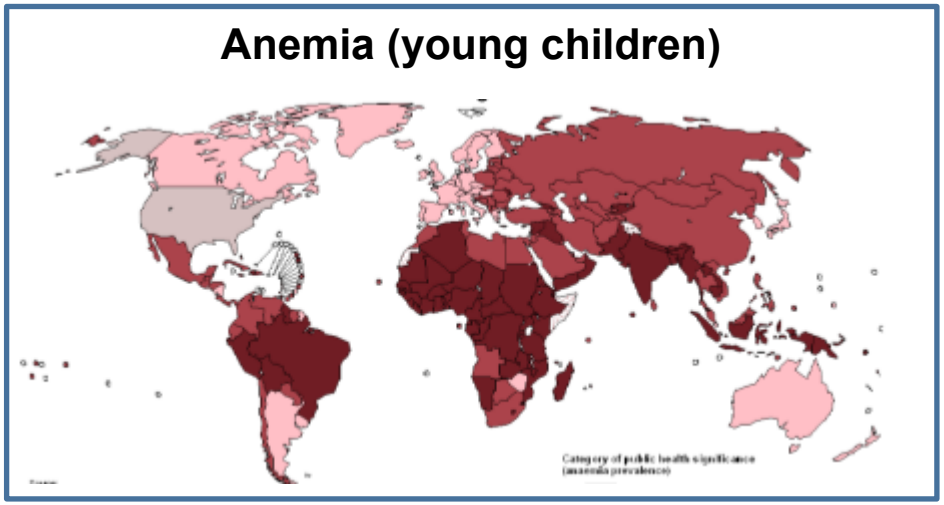


Image sources: Petaholmes based on WHO data; WHO

Cassava is a staple food crop in much of Africa but low in nutrients

Standard white variety

Scientists have recently identified a variant that produces much more vitamin A that the standard variety.

Newly discovered yellow variety

Welsch, R., Arango, J., Bar, C., Salazar, B., Al-Babili, S., Beltran, J., Chavarriaga, P., Ceballos, H., Tohme, J., and Beyer, P. Provitamin A accumulation in cassava (*Manihot esculenta*) roots driven by a single nucleotide polymorphism in a phytoene synthase gene. Plant Cell; tpc.110.077560.

Genetically biofortified foods

Iron-enriched rice

Vitamin A–enriched rice

Wild-type (top) and antioxidant-enriched tomatoes

Plants provide us with more than food

Plants:

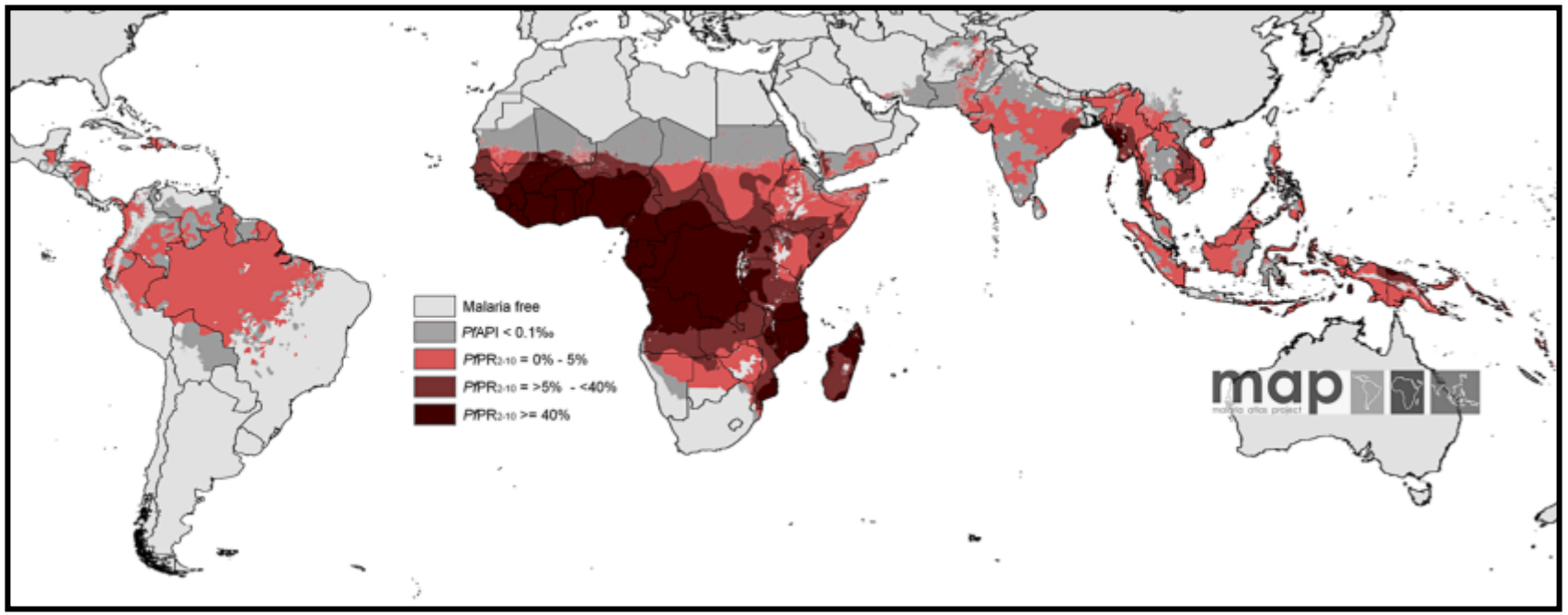
- are sources of novel therapeutic drugs
- provide better fibers for paper or fabric
- are sources of biorenewable products
- provide renewable energy sources

Photo credit: tom donald

Plants produce hundreds of compounds we use as medicines or drugs

- **Willow** (*Salix*) bark as a source of aspirin (acetylsalicylic acid)
- **Foxglove** (*Digitalis purpurea*) as a source of digitalis (treatment for cardiac problems)
- **Pacific yew** (*Taxus brevifolia*) as a source of taxol (treatment for cancer)
- **Coffee** (*Coffea arabica*) and **tea** (*Camellia sinensis*) as sources of caffeine (stimulant)

Malaria kills millions of people



The regions of the world with highest risk for malaria.

Hay, S.I., et al., (2009) PLoS Med 6(3): e1000048. doi:10.1371/ journal.pmed.1000048

The protozoan *Plasmodium* causes malaria

Plasmodium inside a mouse cell

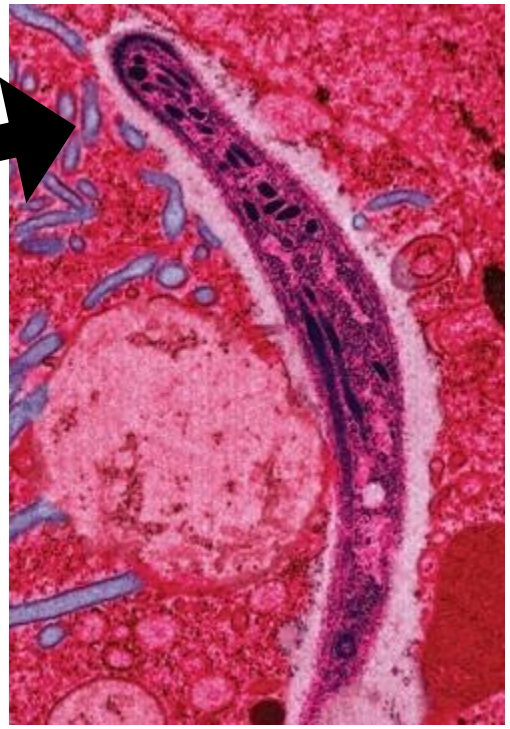
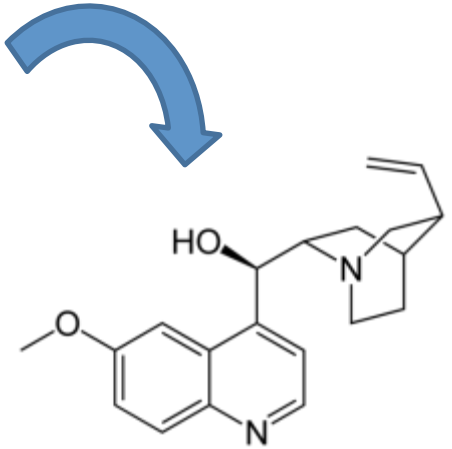


Image by Ute Frevert; false color by Margaret Shear.

Plasmodium is transferred into humans by infected mosquitoes

Photo credit: CDC

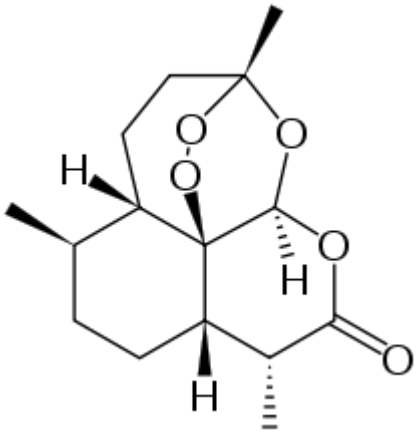
Cinchona tree bark contains quinine, which kills *Plasmodium*



But *Plasmodium* are developing resistances to quinine, so other sources of anti-malarial compounds must be found.

Image credits: Köhler; CDC

Artemisia annua is a plant with novel antimalarial activities



Artemisinin

Artemisia has been used by Chinese herbalists for thousands of years. In 1972 the active ingredient, artemisinin, was purified.

Photo credit: www.anamed.net

Plant scientists are developing higher-producing *Artemisia*

15 JANUARY 2010 VOL 327 SCIENCE

The Genetic Map of *Artemisia annua* L. Identifies Loci Affecting Yield of the Antimalarial Drug Artemisinin

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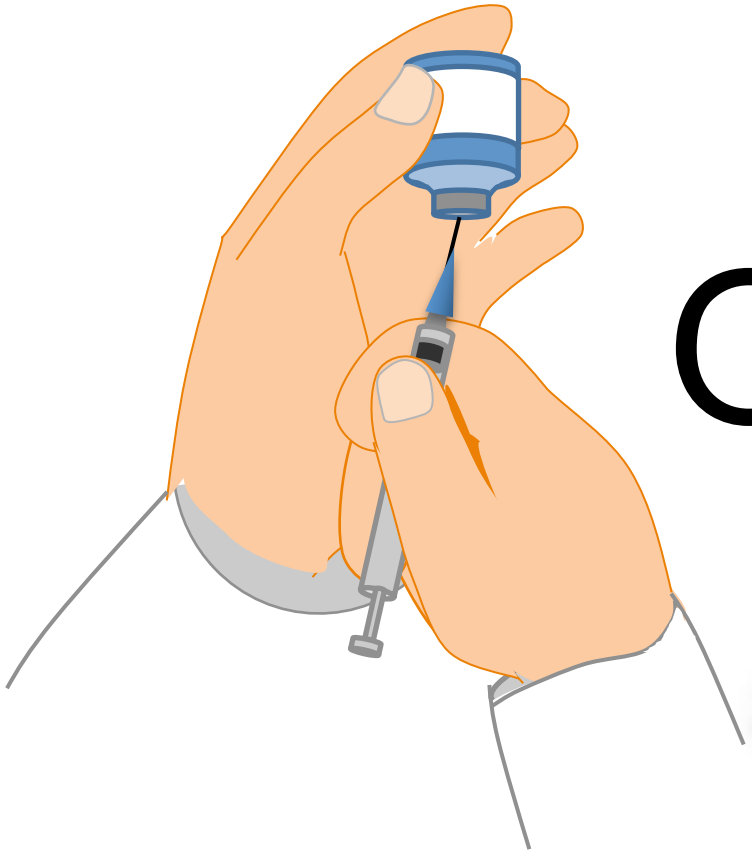
Photo credit: www.york.ac.uk/org/cnap/artemisiaproject/

Plants can make safe and inexpensive edible vaccines and antibodies



OR

?

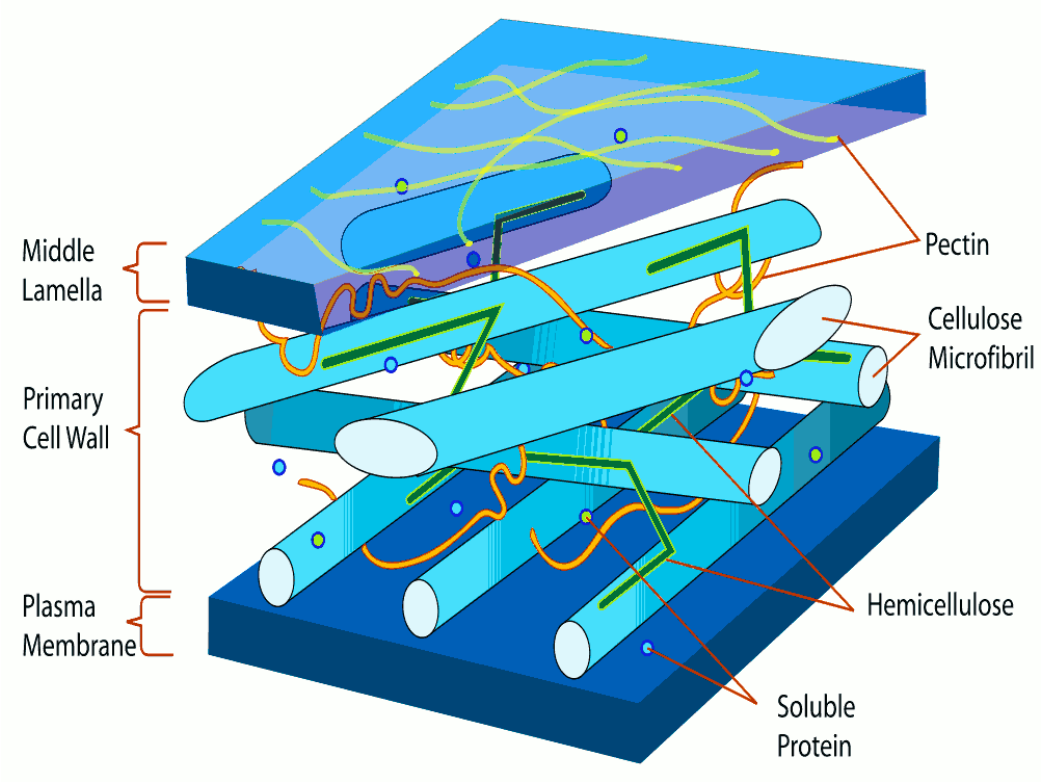
Plant cell walls provide important durable materials

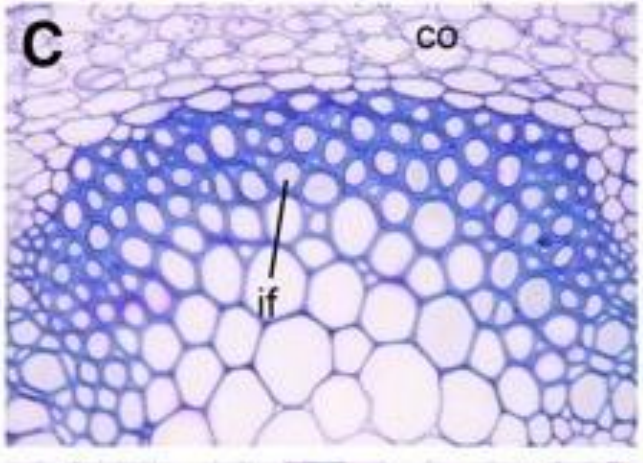
Wood is primarily composed of plant cell walls.

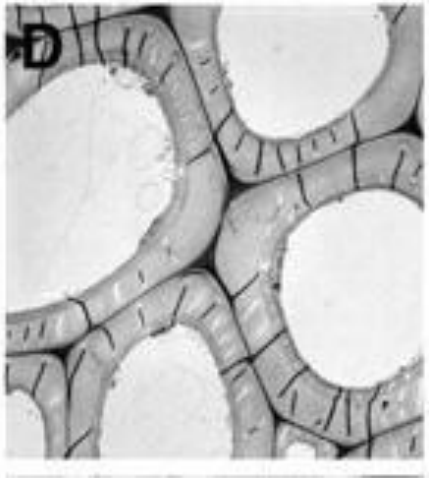
Photo credit: tom donald

Cell walls

Primary plant cell walls are composed mainly of carbohydrates and proteins.



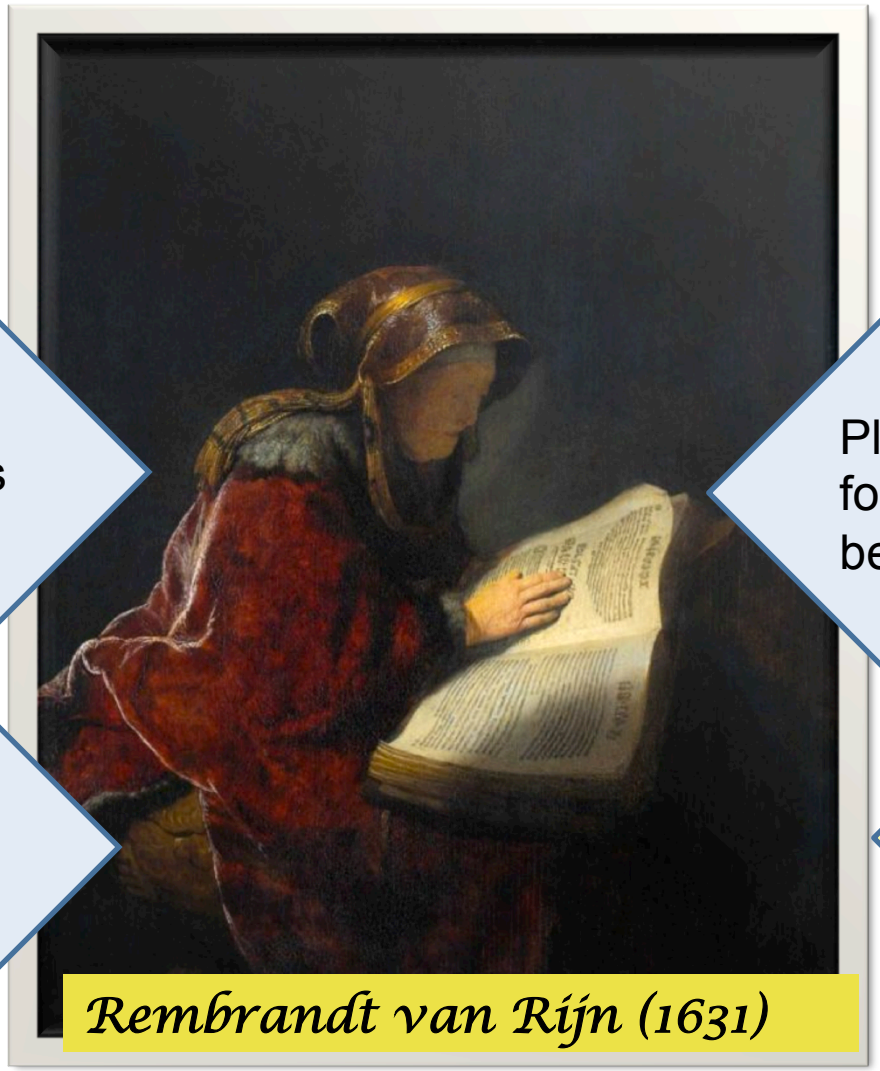




Some cells produce a rigid secondary wall that incorporates lignin, an insoluble cross-linking compound.

Photo credit: www.wpclipart.com/plants; Zhong, R., et al., (2008) Plant Cell 20:2763-2782 .

Wood and fibers are everywhere



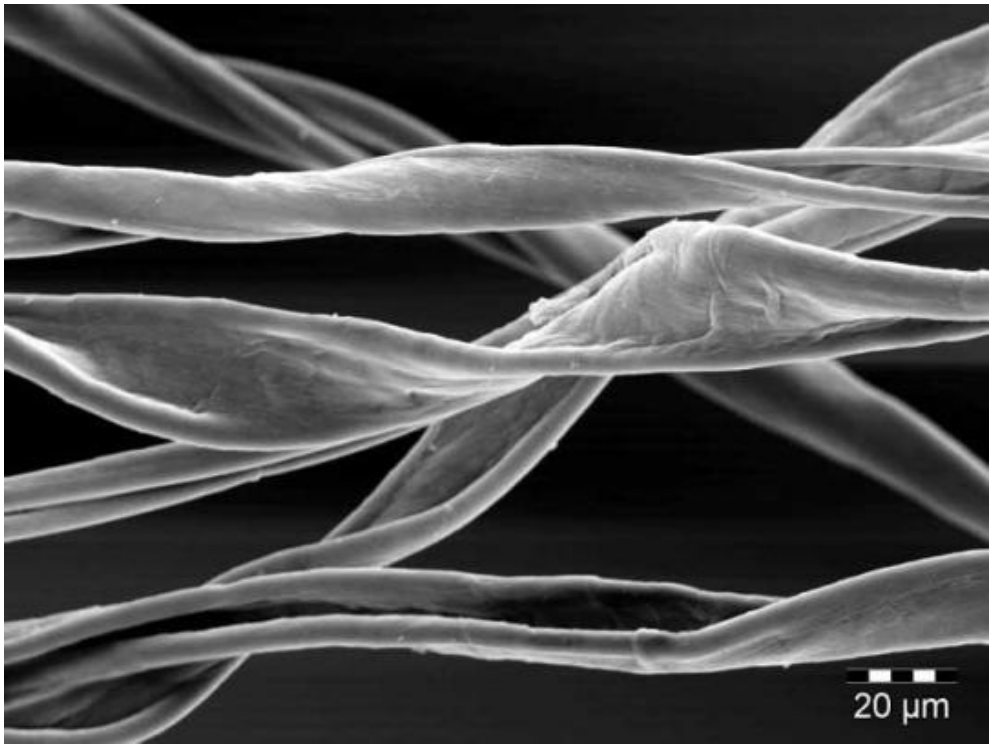
Clothing made from plant fibers (cotton, linen)

Plant fibers are used for making paper, and before that papyrus.

Wood is used for buildings and furniture.

Painting canvas is made from flax or hemp fibers.

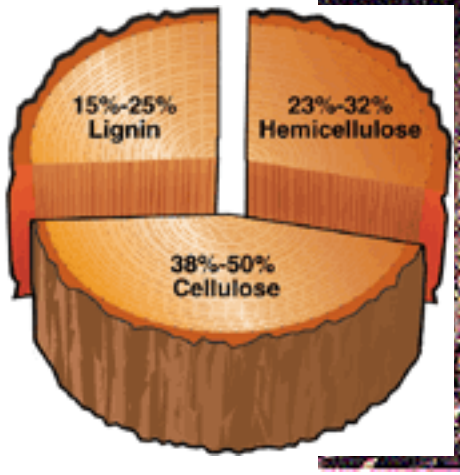
Plants provide fibers for paper and fabric



Cotton is being bred for increased pest resistance and better fiber production.

Photo credits: Chen Lab; IFPC

The genome sequence of poplar, a source of fiber for paper, was recently completed

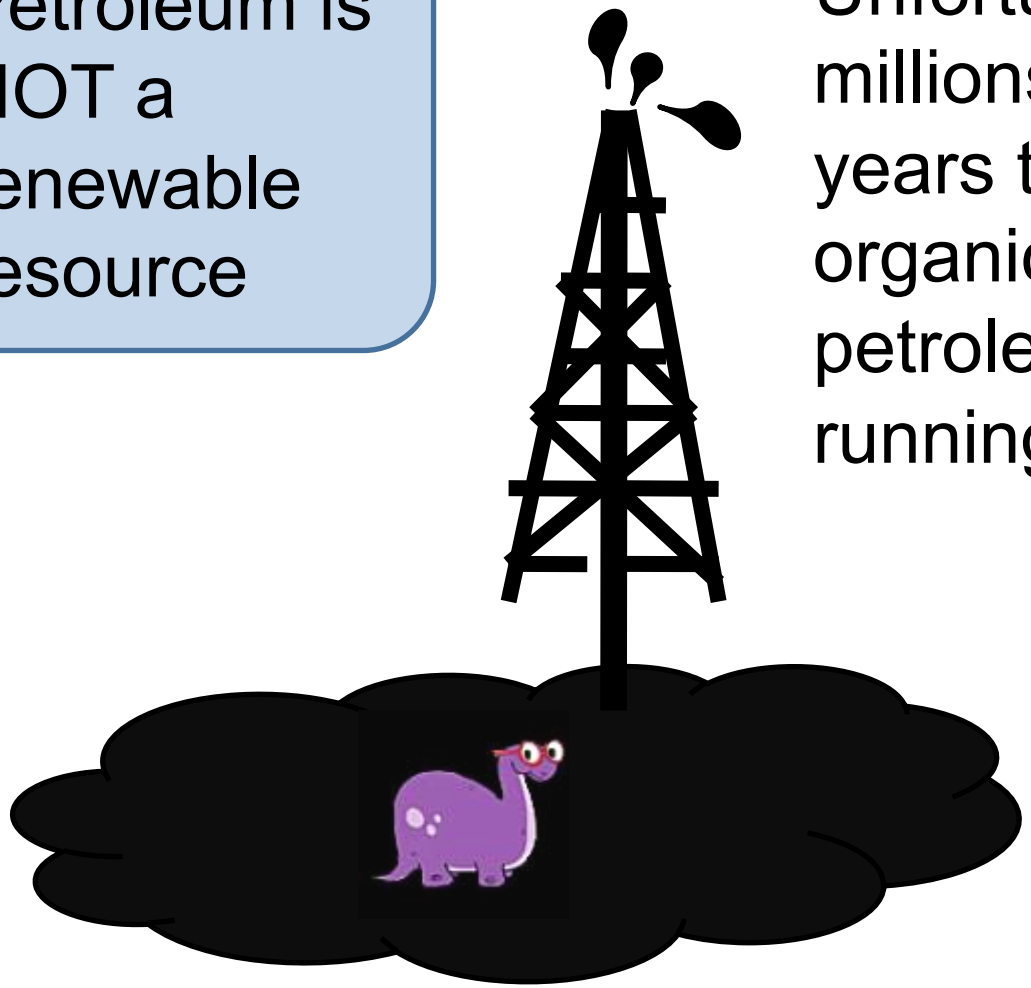


This information is being used to improve the efficiency of paper production.

Photo credit: ChmlTech.com

Plants can replace petroleum for many products and purposes

Petroleum is NOT a renewable resource



Unfortunately, it takes millions and millions of years to convert dead organic material into petroleum...and we are running out of it.

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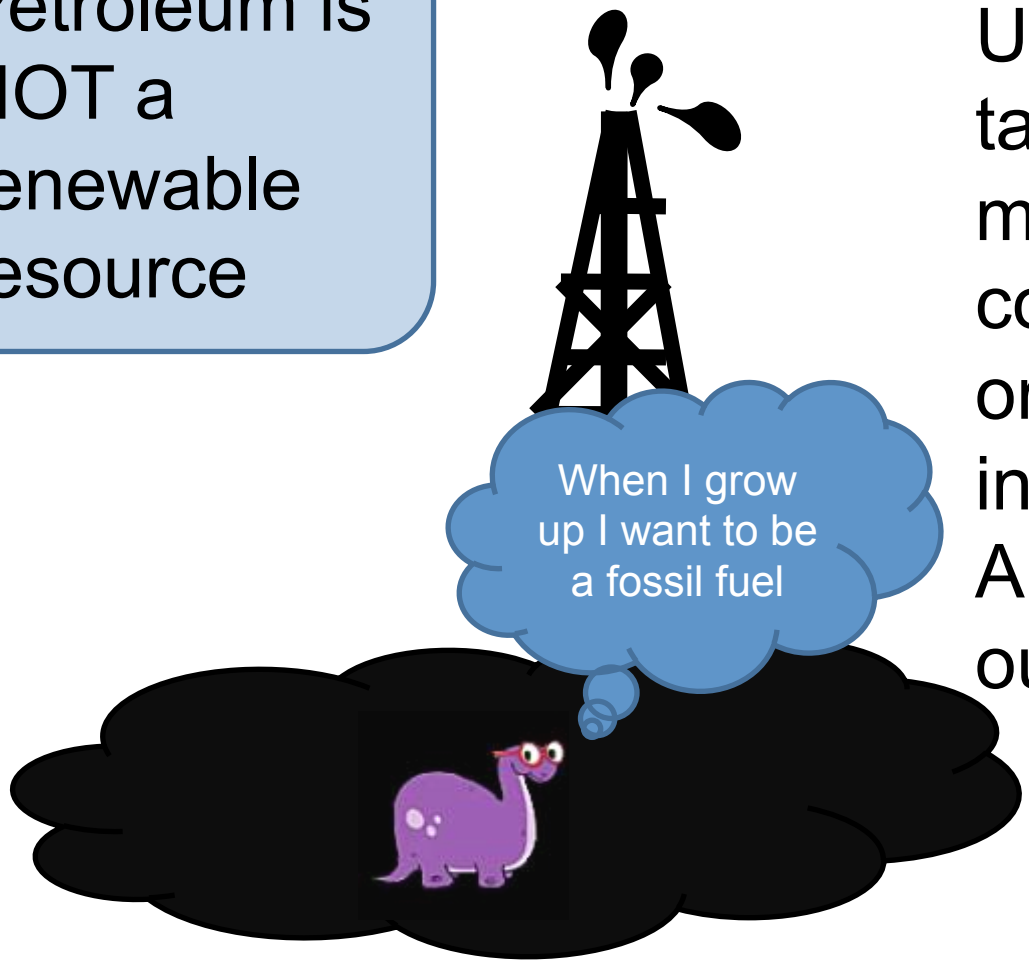

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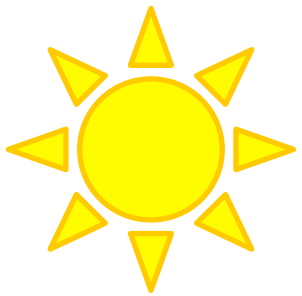
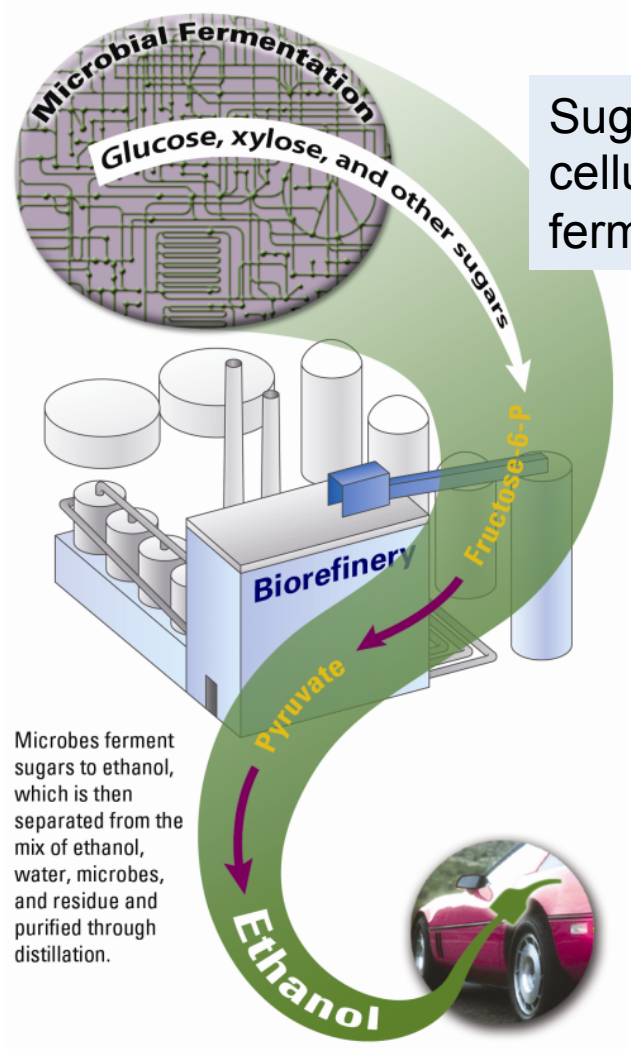
Plants can be a source of biofuels



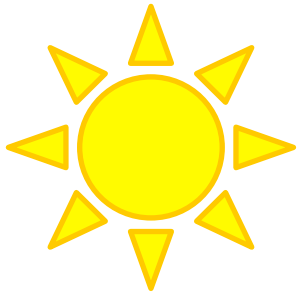
Energy from sunlight



Sugars, starches and cellulose can be fermented into ethanol

Image source: Genome Management Information System, Oak Ridge National Laboratory

Plants can be a source of biodiesel



Biodiesel produced from rape, algae and soybeans are replacing petroleum-derived diesel.

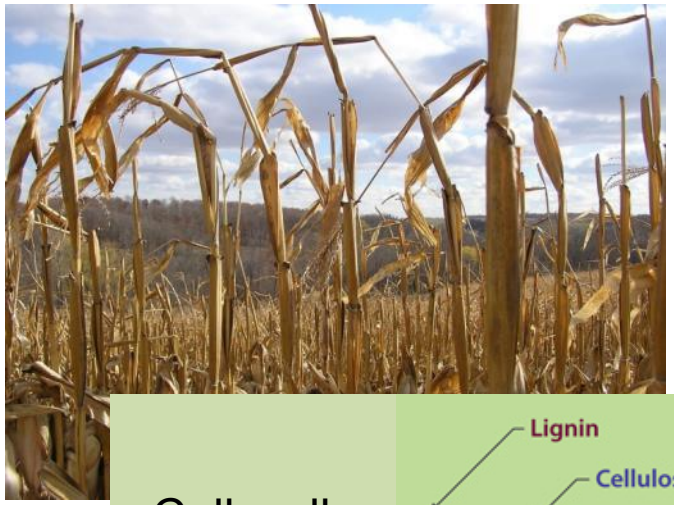
Image sources: Tilo Hauke, University of Minnesota, Iowa State University Extension.

Bioenergy crops should not affect food production or prices

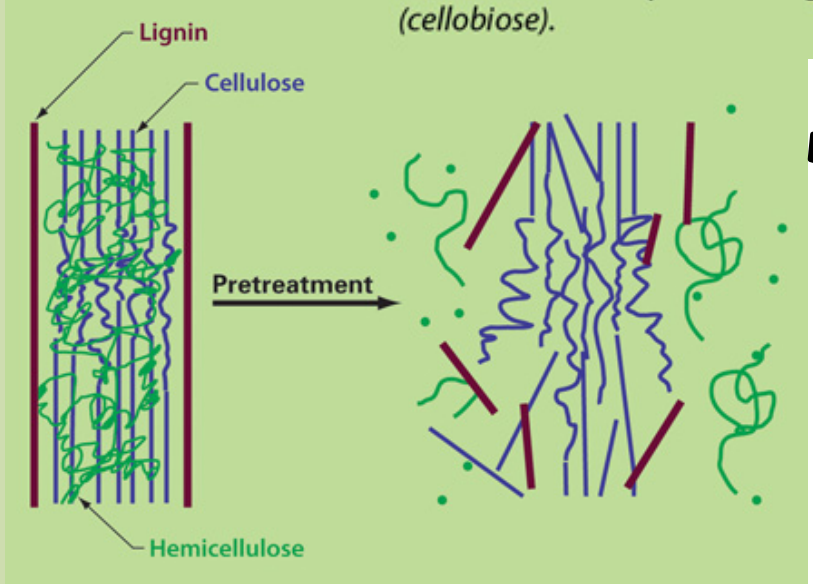
Miscanthus giganteus is a fast growing perennial bioenergy crop that grows on land unsuitable for food production.

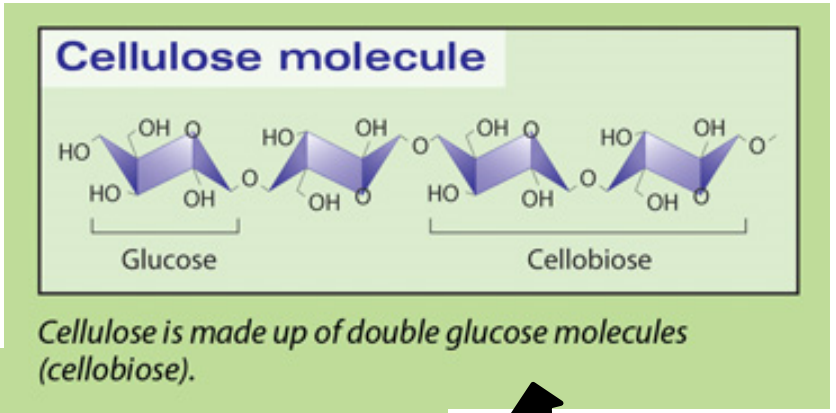
Photo Illustration courtesy S. Long Lab, University of Illinois, 2006

Ethanol isolated from cell wall cellulose is an important energy source



Cell walls from corn stalks and other agricultural residue



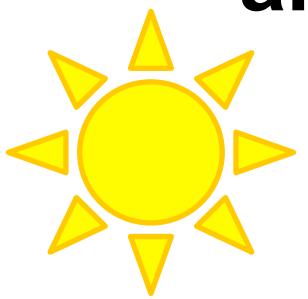


Cellulose is made up of double glucose molecules (cellobiose).

Ethanol

Image source: Genome Management Information System, Oak Ridge National Laboratory

Plants can be sources of biorenewable and biodegradable resources



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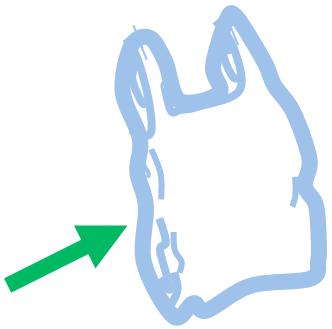
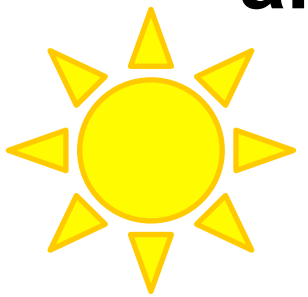


Produce plastics from renewable plant material

Photo Illustration courtesy S. Long Lab, University of Illinois, 2006

Plants can be sources of biorenewable and biodegradable resources



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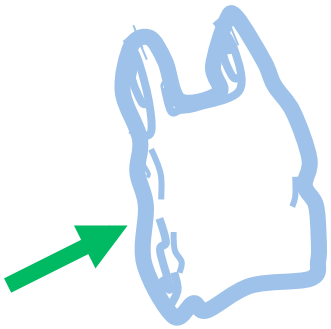

Scientists are investigating cost-effective ways to convert plants into plastics.

Biodegradation

Photo Illustration courtesy S. Long Lab, University of Illinois, 2006

Phytoremediation?

Using living plants for contaminant removal, degradation, or containment

Clean up soil and or groundwater

Can remove organics, metals, leftover pesticides, explosives, radioactive waste

Used independently or with other cleanup methods to reduce costs