5.6 THE GREEN REVOLUTION AND THE IMPACTS OF AGRICULTURAL PRACTICES

College Board Topics 5.3 and 5.4

RSK pg. 244 – 248 and 222 - 223

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

EIN-2

When humans use natural resources, they alter natural systems.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EIN-2.C Describe changes in agricultural practices.	EIN-2.C.1 The Green Revolution started a shift to new agricultural strategies and practices in order to increase food production, with both positive and negative results. Some of these strategies and methods are mechanization, genetically modified organisms (GMOs), fertilization, irrigation, and the use of pesticides. EIN-2.C.2 Mechanization of farming can increase profits and efficiency for farms. It can also increase reliance on fossil fuels.
LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
EIN-2.D Describe agricultural practices that cause environmental damage.	LOR-2.D.1 Agricultural practices that can cause environmental damage include tilling, slash-and-burn farming, and the use of fertilizers.

SUGGESTED SKILL

Concept Explanation

1.A

Describe environmental concepts and processes.

SUGGESTED SKILL

Text Analysis

3.B

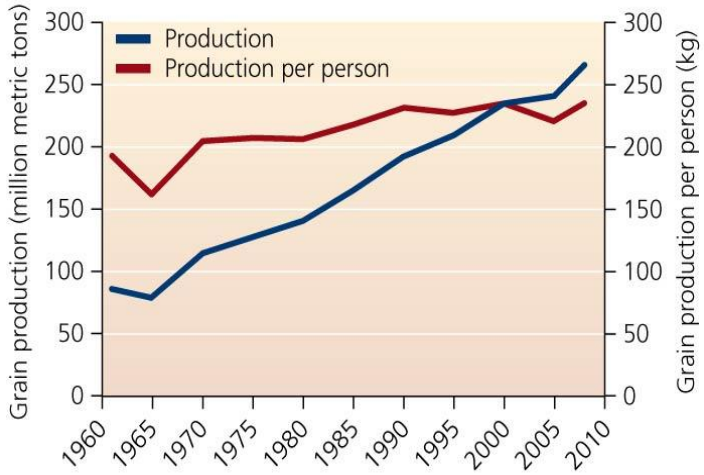
Describe the author's perspective and assumptions.

Feeding the World

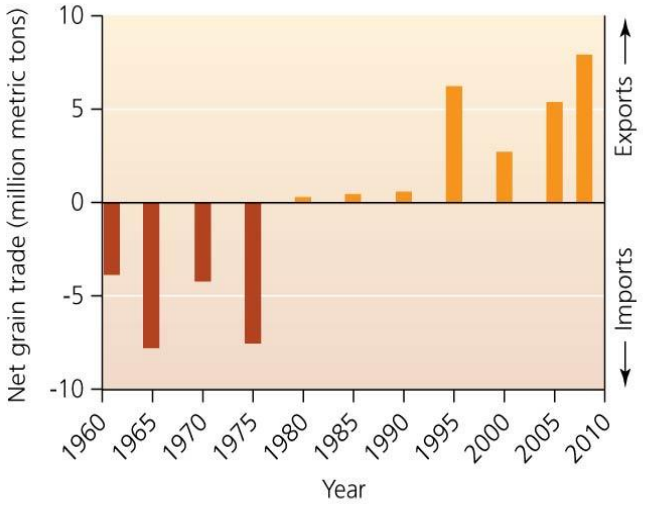
- In the 1930's and 1940's world leaders began to realize that agricultural production could not continue to increase by simply increasing the amount of land being used for agriculture
  - there was not enough land to do this indefinitely.
  - Feeding growing populations would require increasing the ***yield*** (crops per acre)
  - Led to artificial selection and plant breeding to select for, and produce, higher yield varieties of many crops, especially grains (corn, wheat, and rice)
  - As a result, yields of crops in industrialized countries skyrocketed in the 20th century (U.S. increased corn yield 5x)

The ***Green Revolution*** (1950's – 1960's)

- Development of high yield crop varieties and associated industrial farming technologies and their export to developing countries.
  - Seen as a way to end world hunger (***Malnutrition and Undernutrition)***
  - Led to a shift in agriculture away from small family run farms and subsistence farming to large industrial scale agribusiness
- Norman Borlaug developed a new strain of wheat and introduced it to Mexico.
  - The new variety of wheat produced more grain per plant, was more disease resistant, and shorter and resisted wind damage better
  - In two decades Mexico tripled wheat production and went from wheat shortages to being a wheat exporter
  - Borlaug took his wheat to India and other parts of Asia with similar success in increasing yields.
  - Borlaug won a Nobel Prize for his work in plant breeding that led to the new variety of wheat.
- The increased productivity of the Green Revolution changed the way we farm.



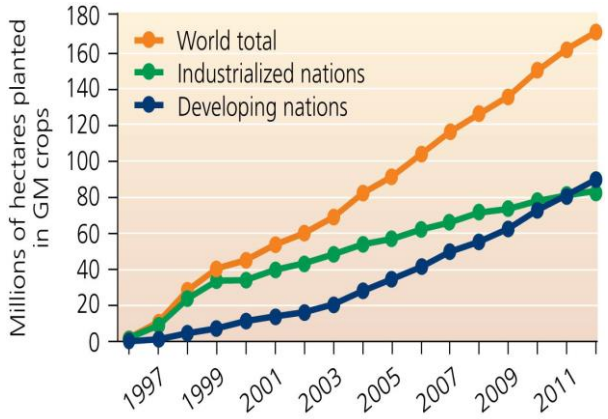
(a) Production and per-capita production rose

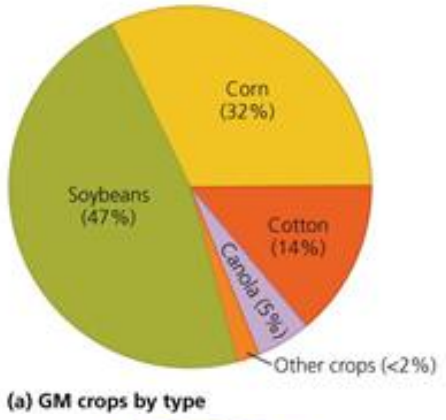


(b) Imports turned to exports

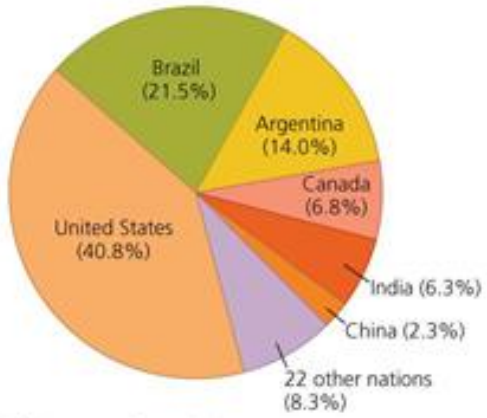
*Grain Production in India

Modern Crops



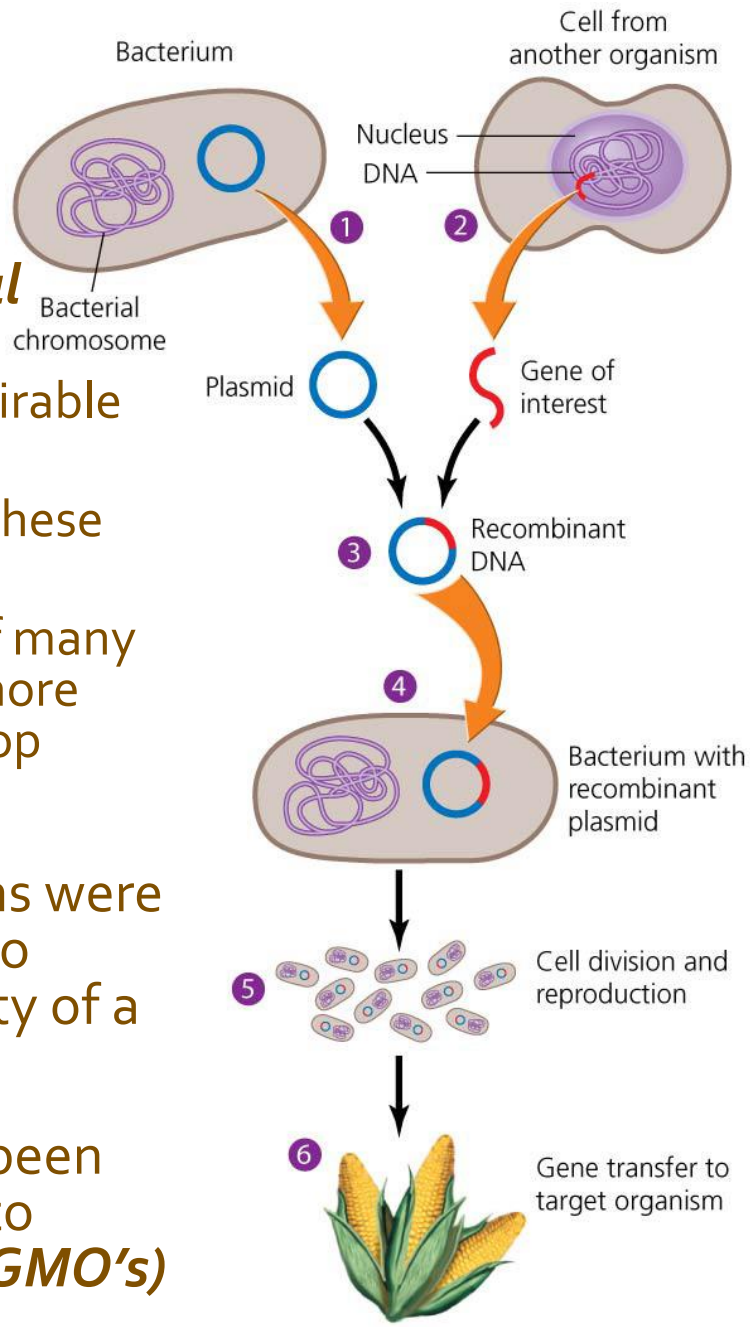


(a) GM crops by type



(b) GM crops by nation

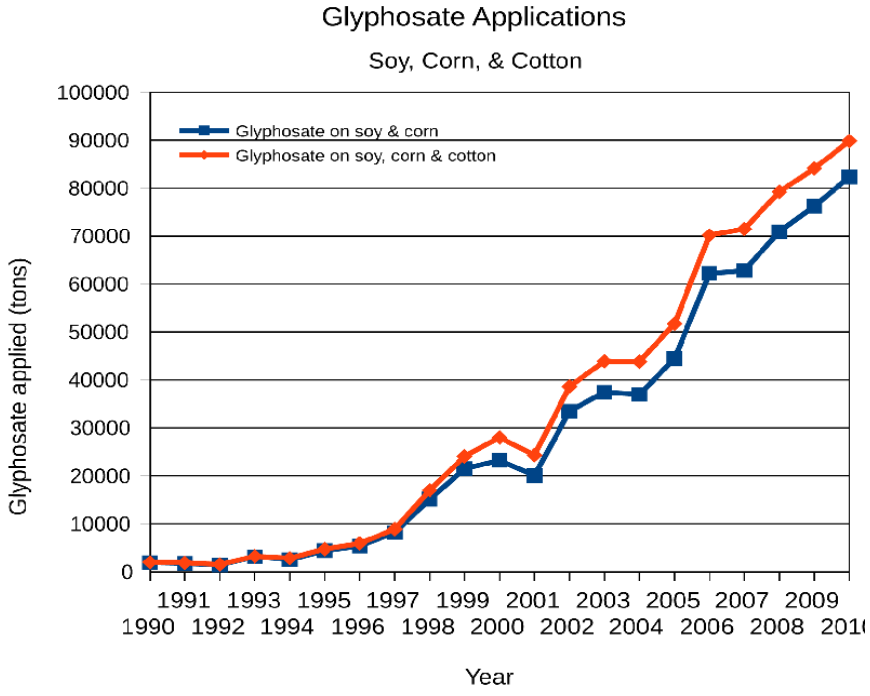
- New strains of crops with greater genetic potential were developed through ***artificial selection.***
  - Individuals in a population with the most desirable traits are selected and allowed to breed.
  - This favors the production of offspring with these same desirable traits.
  - Over time we have created genetic strains of many crop species that have some traits that are more desirable than ancestral varieties of these crop species.
- Seeds from these artificially selected strains were highly sought after and in many cases led to fields planted in only a single genetic variety of a single crop species.
- Artificial selection and plant breeding has been largely replaced with genetic engineering to produce ***genetically modified organisms (GMO's)***



Example GM Crops

Bt-Crops

- Lepidoptera larvae, in particular, European corn borer, are caterpillars that destroy corn and other important crops
- A naturally occurring soil bacterium, *Bacillus Thuringenisis* contains a gene that produces a protein called Bt delta endotoxin
- Bt delta endotoxin kills Lepidoptera larvae, in particular, European corn borer.
- This gene has been successfully inserted into the genome of corn and other crop species
- BT crops now produce their own insecticide



Round-Up Ready Crops

- Soy, corn, cotton, alfalfa and more.
- Glyphosate is the active ingredient in the herbicide, Round-up.
- Glyphosate is an inhibitor of a key enzyme in the biosynthesis of certain amino acids in all plants.
- *Agrobacterium* contain a version of this biosynthesis enzyme that is not inhibited by Glyphosate.
- The makers of Round-up also sell crop seeds engineered with the Glyphosate resistant version of the enzyme from agrobacterium
- Allows farmers to use higher doses of the herbicide Round-up without killing the crop plants also.

Pros and Cons of Genetically Modified Organisms

Benefits of GMO's

- Increased yield with lower costs
  - Greatly enhances food security for society
  - Decreased deforestation/land conversion result, which helps maintain overall biodiversity
- Reduced use of chemical insecticides since plants produce their own insecticides (like Bt)
  - Bt cotton in India increased yields , while lowering pesticide use.
  - Round-up ready crops have had the opposite effect.
- Many useful possibilities:
  - Expand the range of tolerance of crop species (heat/cold, drought, salinity)
  - Increase density at which crops will grow (↑ yield per acre) less area needed for agriculture.
  - More resistant to shipping damage (square tomatoes)

Cons of GMO's

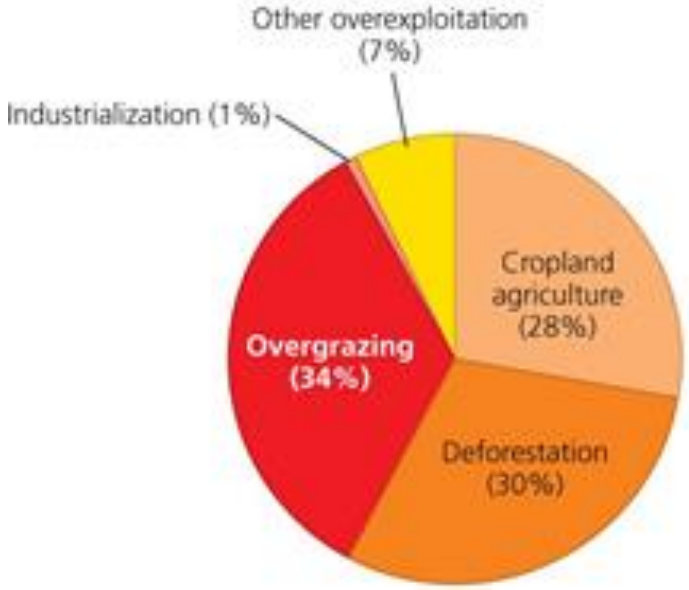
- Public concerns over health effects of GMO's
  - Little research to support the feared negative health affects of GMO's
  - Increased use of pesticides on GMO's and the effect of the pesticides on human health may be a valid concern however.
- Concerns over ecological impacts of domesticated GMO's breeding with wild relatives
  - Production of super weeds and further loss of genetic variation among wild relatives.
  - Some varieties are engineered with a "terminator" to make GM seeds sterile
- GM varieties with terminator genes require farmers to purchase new seeds each growing season rather than use seeds produced by the previous seasons crops
- Most commercialized GMO's focus on pesticide production or herbicide resistance not on improving nutrient content, drought resistance, or salinity tolerance)
- There is no requirement to label GM foods and it is often difficult to determine when a product contains GMO's

Artificially selected varieties and GMO's have led to monocultures

- Benefits of a ***monoculture***:
  - Easy to plant (all same species, with same duration growing season, and same time to maturity and harvest)
  - Easy to maintain (require same amount and frequency of water, fertilizer and pesticides)
  - Easy to harvest (same growth form makes mechanizing the harvesting procedure easier to engineer)
- Drawbacks of monocultures:
  - Greatly decrease biodiversity (more prone to pests, fewer natural predators, decreased habitat for other species in the area)
  - Increase risk of catastrophic crop losses due to lower genetic diversity.
  - Increase soil degradation through nutrient depletion.
  - Increased dependence on synthetic pesticides and inorganic fertilizers.

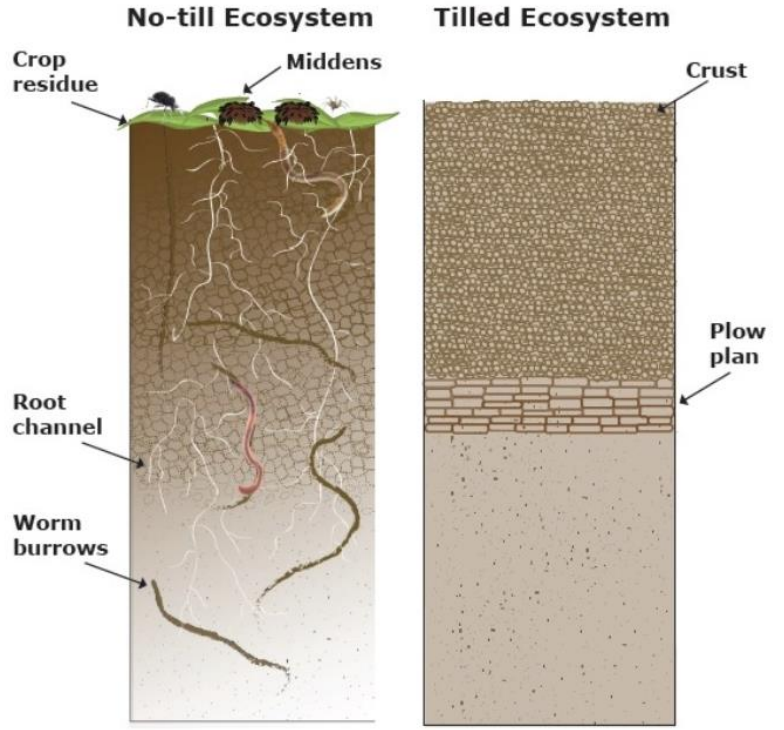
Increased soil degradation

- ***Soil degradation***
  - a decline in soil quality and productivity leading to a loss of ***arable land*** (land suitable for agriculture).
  - Soil degradation results from nutrient depletion, erosion, compaction, waterlogging, and salinization
  - In severe cases soil degradation can lead to ***desertification*** (permanent decrease in productivity exceeding 10%).
  - Over the past 50 years, soil degradation has reduced potential food crop production by 13%.
- Human activities, including deforestation, cropland agriculture and grazing are leading causes of soil degradation worldwide.
- The "Dust Bowl" refers to both a major soil degradation event and an important agricultural region of the U.S. that is prone to continued soil degradation.



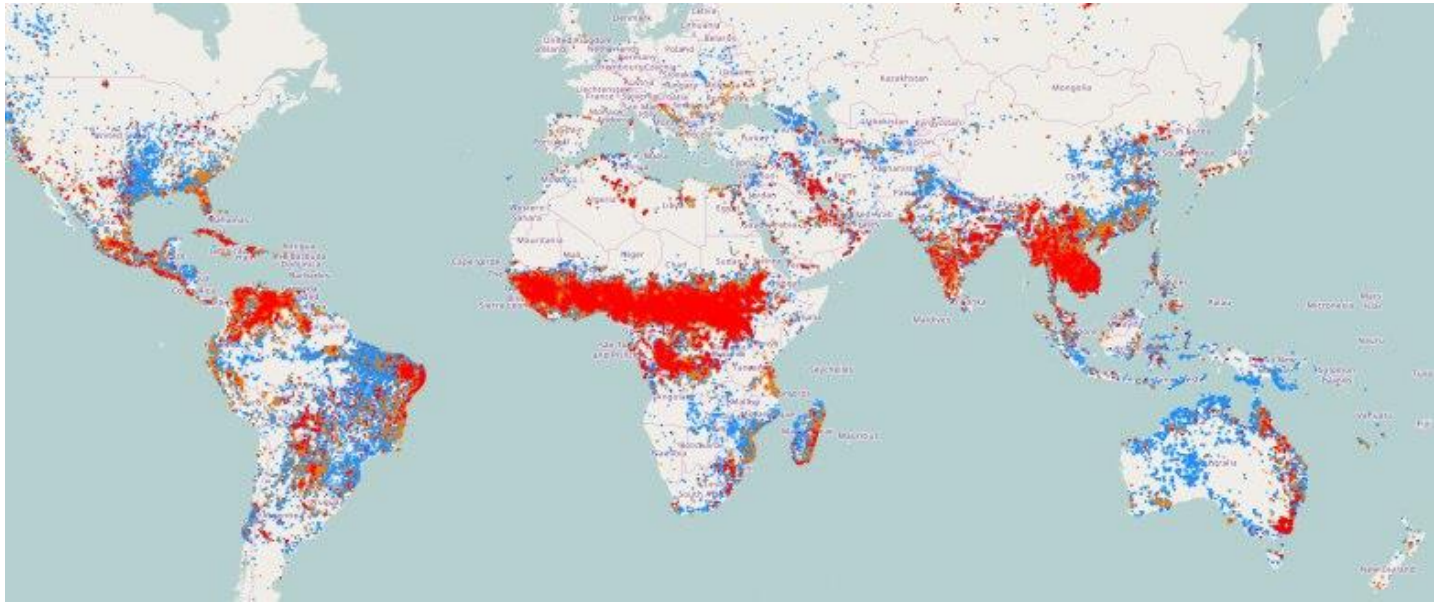
Tilling increases erosion and can lead to soil degradation

- Tilling fields removes weeds and loosens soil before the next planting season.
  - Tilling mixes and breaks up the topsoil to make planting easier and loosens the soil to promote aeration and root development.
  - Increases erosion by loosening soil; breaks up left over root structure from the previous harvest
    - Leads to loss of organic matter and topsoil nutrients over time and releases CO_2.
    - Erosion caused by tilling can lead to sedimentation and eutrophication of surface waters.
  - Tilling is usually done with heavy machinery.
    - compacts the subsoil (B horizon) even while loosening the topsoil.
    - Increases dependence on fossil fuels (extraction and emissions)



Tropical Soils are susceptible to soil degradation

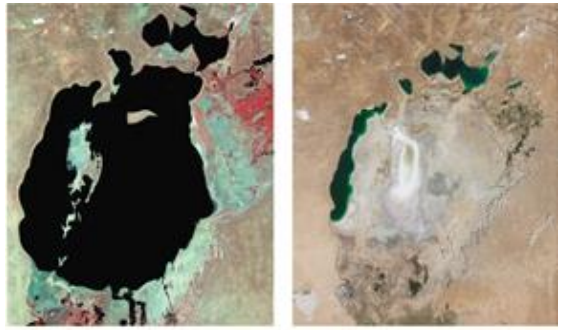
- Thin nutrient poor soils resulting from the rapid rate of decomposition (warm, wet climate) and extremely high productivity of rain forest vegetation (plenty of sun and rain).
  - Nutrients are stored in the tissues of rainforest plants, not the soils
  - Clearing rain forests for agriculture would remove the nutrients with the vegetation. Burning the cut vegetation on site returns some of the nutrients to the soil in the ash. (***slash and burn agriculture***)
  - Abundant rainfall in the tropics quickly erodes soils and leeches the remaining nutrients from the soil.
- Forces farmers to move to new fields frequently by clearing more land (every 3 to 5 years in many cases)



Worldwide fire activity Dec 15, 2020 – January 15, 2020. Most fires in Central, and South America, Africa, and SE Asia are intentional slash and burn fires.

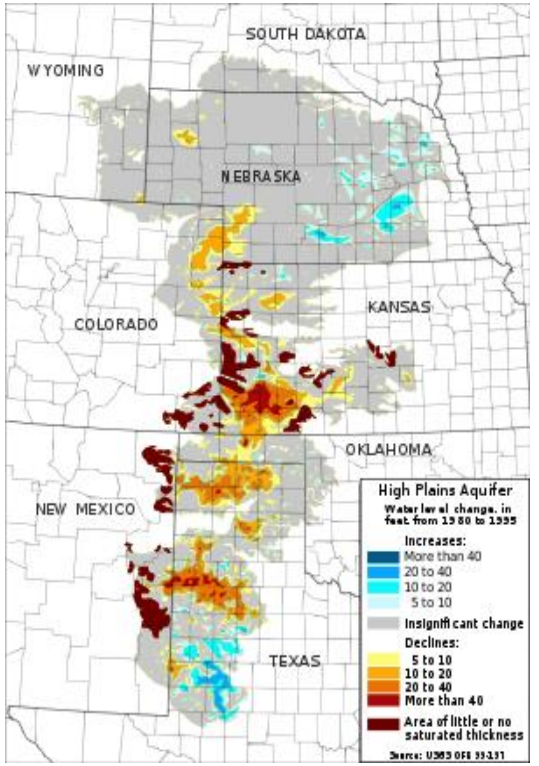
Increased need for irrigation

- As industrial agricultural practices spread to more marginal agricultural lands the demand for irrigation has increased.
  - Crops in arid climates require more irrigation water.
  - New strains of crops required require more water to reach their genetically engineered potential.
- Increased irrigation has led to:
  - Water diversion projects to support agriculture in more arid regions.
    - Worldwide, 15%–35% of water withdrawals for agriculture are unsustainable
    - Lower Colorado River Basin, Aral Sea, Ogallala aquifer
  - Overwatering can lead to ***water logging*** of soils and ***soil salinization***



(a) Satellite image of Aral Sea, 1987

(b) Satellite image of Aral Sea, 2009



- The Colorado river often runs dry
- The two rivers leading into the Aral Sea were diverted to irrigate rice and cotton fields
- Water levels in the Ogallala aquifer have dropped by over 40 feet in some regions

Water for Irrigation

- Globally, 70% of water is used for agriculture, 20% for industry, and 10% for residential and municipal use.
- We use 70% more irrigation water than 50 years ago
  - Rapid population growth and higher standards of living requires more food and clothes
- Water use for agriculture is cheap due to government subsidies and farmers have little incentive to conserve.
- Irrigation can more than double crop yields
  - But, irrigation is often highly inefficient (runoff, overspray, and evaporation)
  - Over-irrigation leads to waterlogging and salinization

Furrow irrigation in the California desert

Increased dependence on inorganic fertilizers

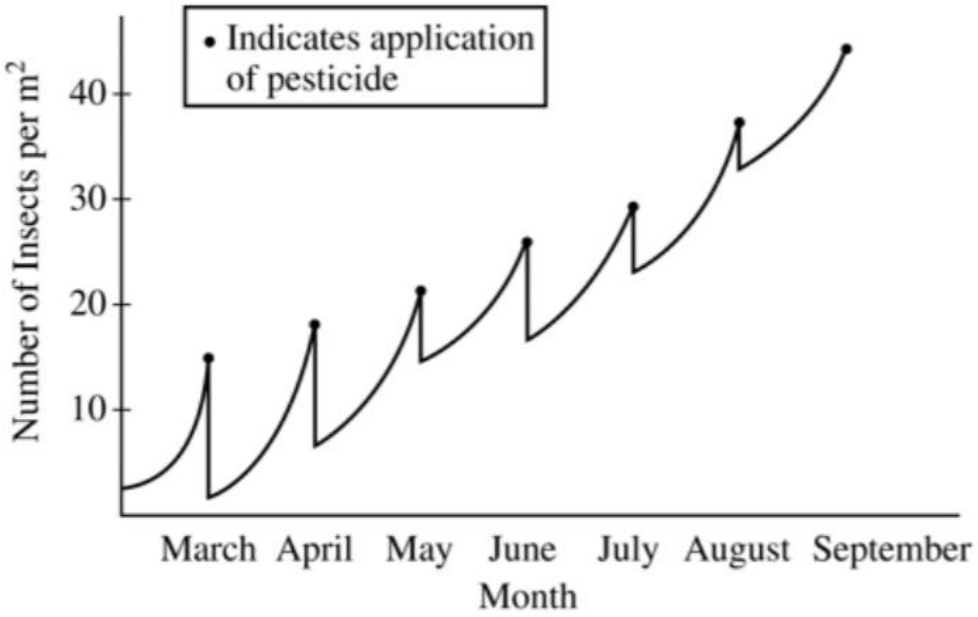
- Increased dependence on inorganic fertilizers increased agricultural yields during the Green Revolution by providing concentrated doses of the macronutrients most needed for plant growth (N,P, K).
  - Phosphates (PO_4^{3-}) are mined from inorganic phosphate deposits
  - Nitrogen based fertilizers are produced through the Haber-Bosch process
    - $3H_2+N_2 \rightarrow 2NH_3$
  - Water soluble granules of fertilizers can be broadcast over soils or dissolved in water and sprayed in precise doses that are customizable to the target crop species.

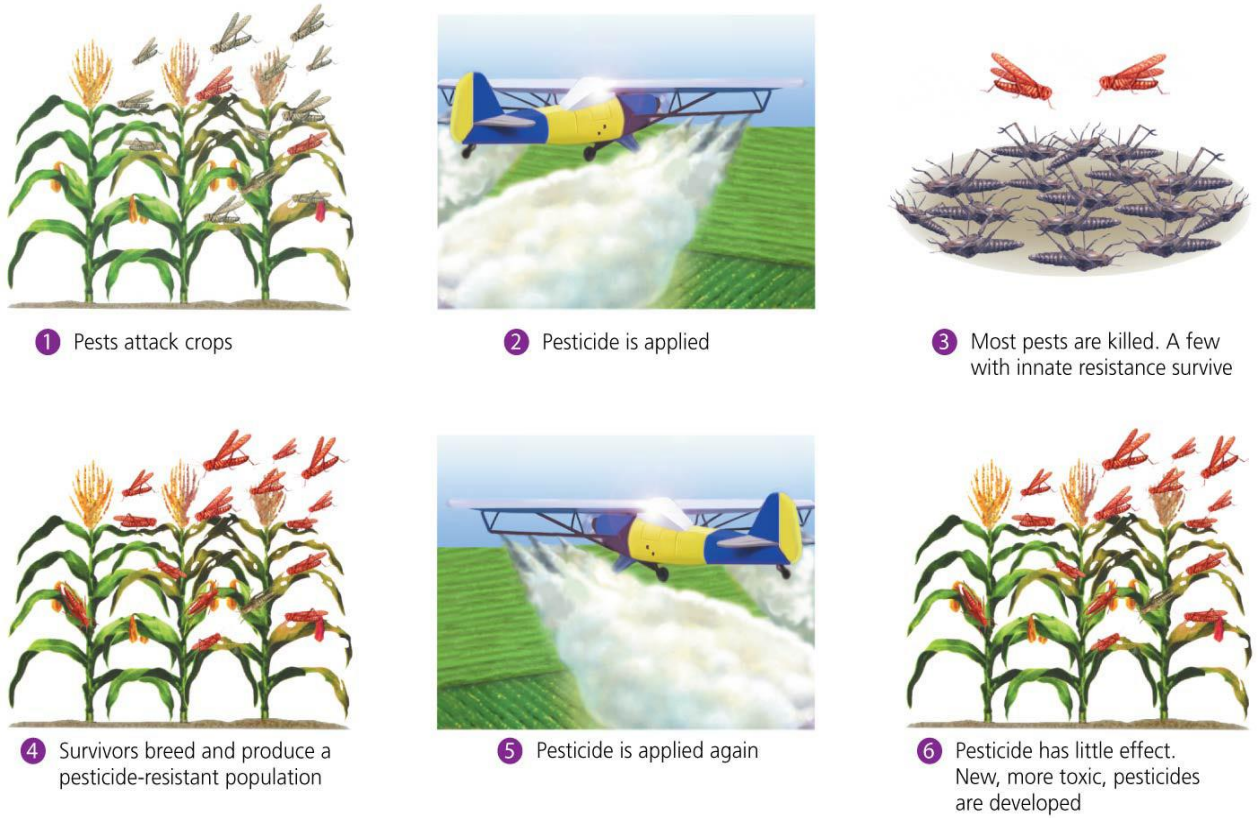
- Water soluble, inorganic fertilizers are also more prone to leeching and runoff.
  - Leeching can contaminate groundwater where increases of nitrogen can lead to increases in some forms of cancer and cause ***blue-baby syndrome*** (methemoglobinemia) which can asphyxiate infants.
  - Fertilizer-enriched runoff from fields can lead to eutrophication of surface waters.
  - Inorganic fertilizers require large amounts energy from of fossil fuels to mine and manufacture (Haber Bosch).

Industrial farming increases the use of synthetic chemical pesticides

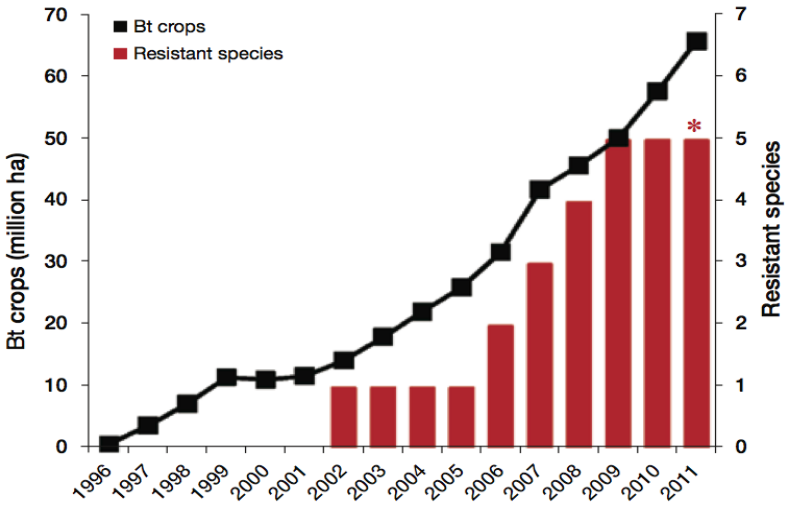
- Industrial farming and its monocultures limit the ability of natural mechanisms to control pest populations
  - Monocultures make it easy for rodents, insects, fungi, and viruses to quickly spread through a field.
  - Simplified ecosystems of industrial farms means there are few, if any, natural predators of pest species.
  - Plowed fields represent disturbed ecosystems primed for colonization by many "weedy" early successional plant species that compete with crops for resources
- Many pesticides are ***broad-spectrum*** chemicals that are toxic to non-target species as well as the pest species.
  - Loss of pollinator species, especially bees, often results from increased use of insecticides.
  - Pesticide may get washed off of fields by precipitation into surrounding areas and water ways where they impact other species.
  - Many pesticides are fat soluble and difficult to metabolize, allowing them to biomagnify / bioaccumulate as they are transfer through food chains.
  - Toxic pesticides can directly threaten human health during application to fields or as a result of pesticide drift.

The Pesticide Treadmill





- Increased use of chemical pesticides has led greater pesticide resistance among pest populations.
  - Artificial selection drives evolution of pesticide resistance and results in even greater use of chemical pesticides
- Pest species can evolve resistance to chemical pesticides relatively quickly
  - Short generation times, r-selected, high mutation rates.



Increased Mechanization

- Large scale industrialization of farming required greater dependence on machinery, and a move away from human and animal powered agriculture.
  - Tractors for tilling fields and towing fertilizer and pesticide sprayers, as well as combines for harvesting.
  - Increased need for fossil fuels and increased emissions of greenhouse gases.
  - Increased impacts from fossil fuel extraction
- Increased dependence on manufacturing of synthetic pesticides and inorganic fertilizers
  - Manufacturing of these synthetic chemicals leads to grater consumption of fossil fuels and greenhouse gas emissions.
  - Many pesticides are petroleum based products.

The Green Revolution and the Impacts of Modern Agriculture

- The greatly increased food production brought on by the Green Revolution has decreased world hunger, increased food security, and increased Earth's carrying capacity for Humans.
  - Yield per acre increased significantly during this time but are the gains made sustainable in the long run
- The Green Revolution introduced the world to the farming techniques of large scale, industrialized agribusiness and with it have come many challenges to environmental quality that threaten the sustainability of modern agriculture.

Video Resources

- Norman Borlaug and the Green Revolution
  - https://www.youtube.com/watch?app=desktop&v=Lg9-HTtgFOk
- Agriculture
  - https://www.youtube.com/watch?v=OGfo4jPEaTo&feature=emb_logo