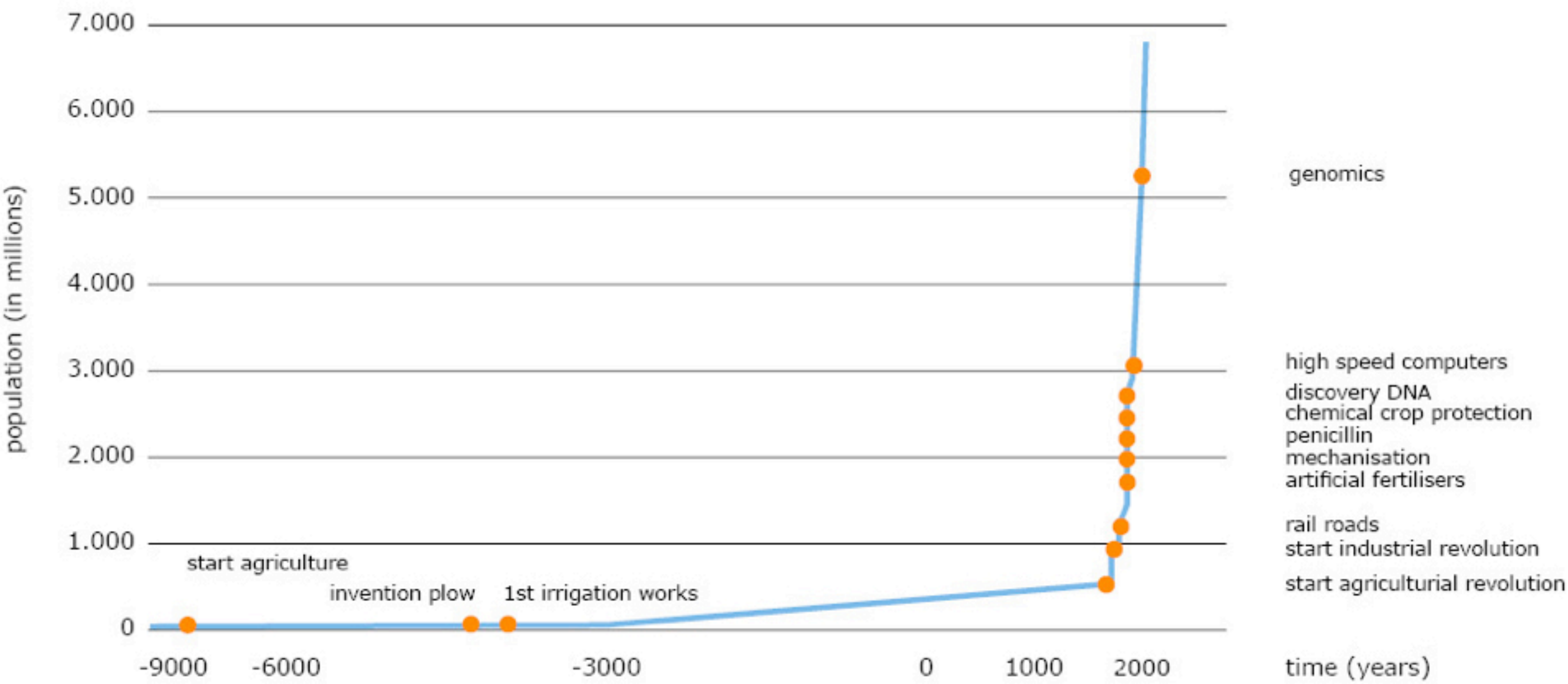
Agroecology: a new view of agriculture and agroecosystem

Corinne Robert (INRA, ENS) and David Claessen (ENS)

Agriculture

Historical context



Adapted from: Fogel R. W., The Escape from Hunger and Premature Death (2004)

From agricultural revolution to industrial revolution

British Agricultural Revolution : unprecedented increase in agricultural production in Britain due to increases in labour and land productivity between the mid-17th and late 19th centuries.

Attributed to social, economic and technology changes

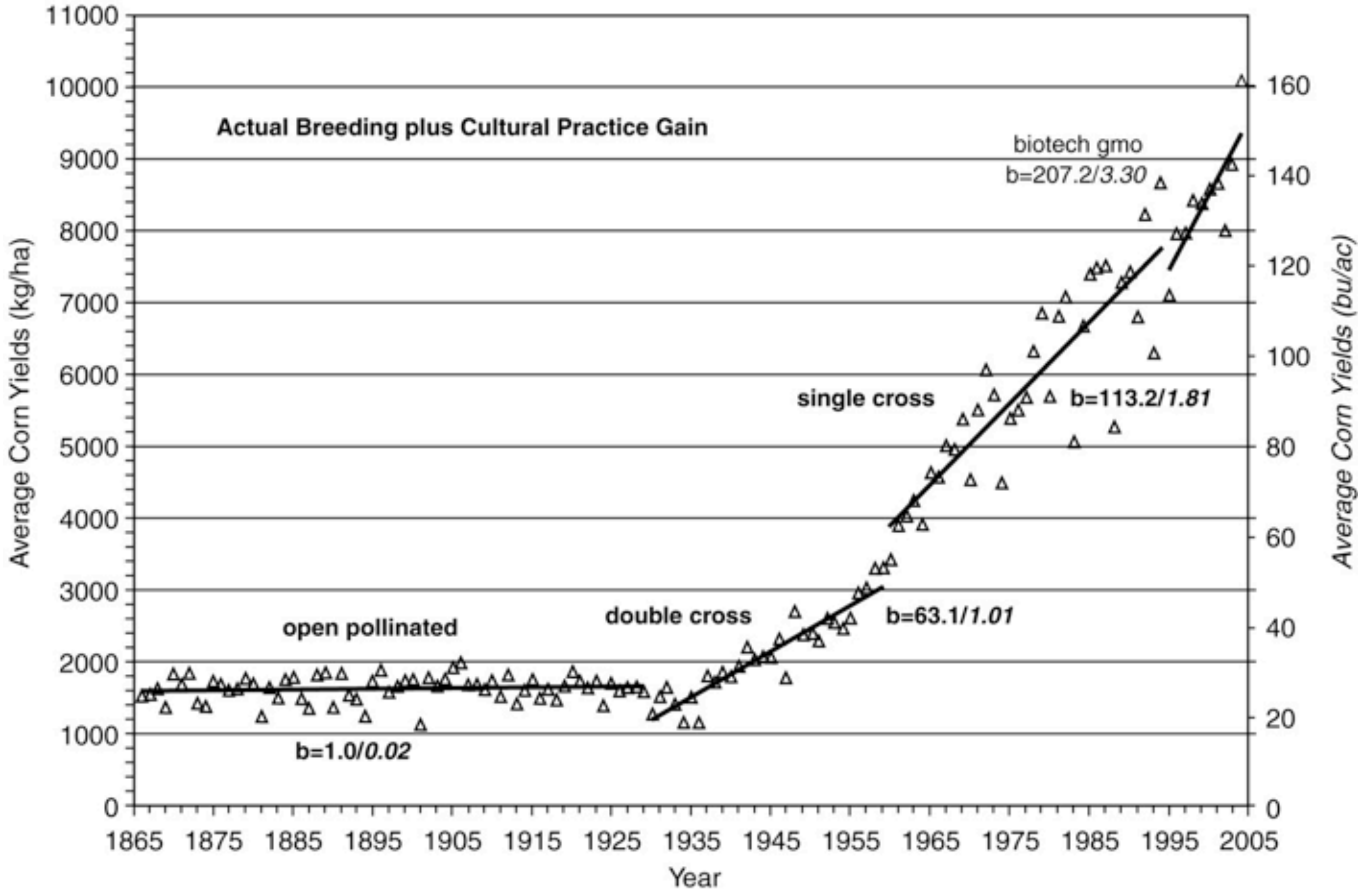
- Crop rotation: Fodder crops, particularly turnips and clover, replaced leaving the land fallow
- Improved Chinese plough (pulled by fewer oxen or horses)
- Transportation infrastructures (roads, canals, railways)
- Land conversion, land drains and reclamation
- Increase in farm size
- Selective breeding

More and more food, less farmers: industrial revolution

Industrial revolution accellerated agricultural revolution:

- Tractors

History of corn yield

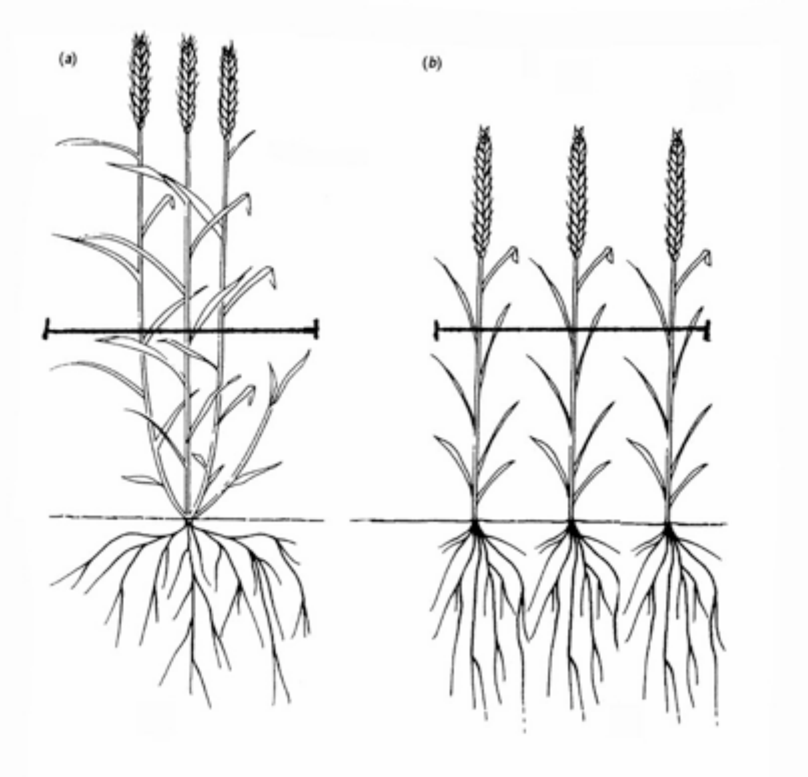


Green revolution

- 1930s-1960s
- Normal Borlaug (1940s)
- Breeding of high-yield crop varieties
- Synthetic fertilizers
- Synthetic pesticides
- Expansion of irrigation
- Modernization of management techniques
  - Monoculture, dependence on fertilizers and pesticides
  - Breeding under the assumption of fertilizers and pesticides

Plant selection: wheat example

- Ideotype: idealized plant type to achieve high yield in a specific environment and cropping system
- Traits:
  - short stem (no lodging... but less competitive)
  - fewer leaves (just enough to intercept available light)
  - single, nonbranching stem (don't waste resources contesting space with neighbors)
  - early flowering (longer grain fill period)
  - high harvest index (more grain, less leaf+stem)
  - erect leaves (spreads available light over more leaf area)



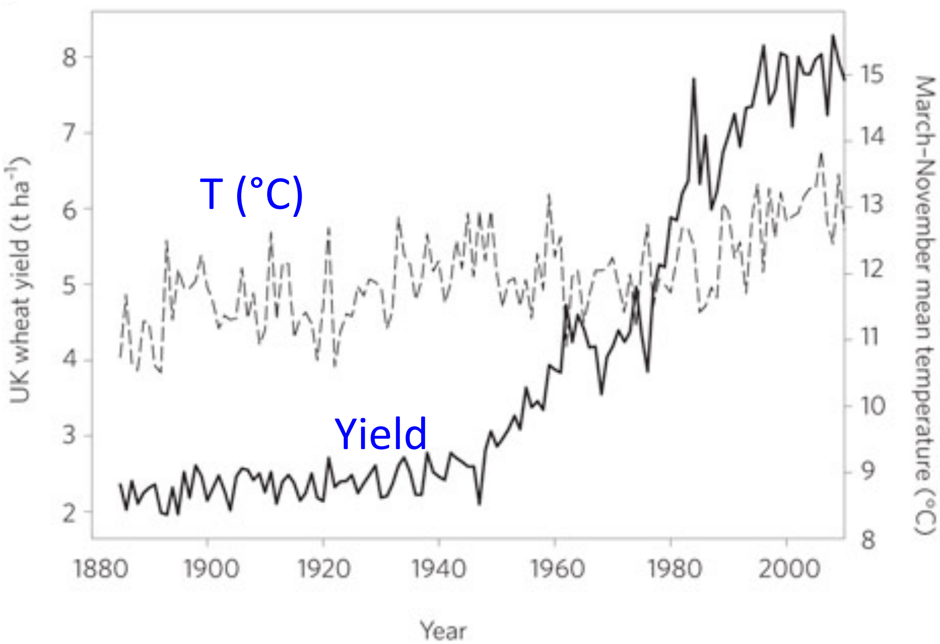
From: **Paul Gepts** (UC Davis) http://www.plantsciences.ucdavis.edu/gepts/pb143/Lec13/PB143L13.htm

Pieter Breughel, 1565, *The Harvesters*

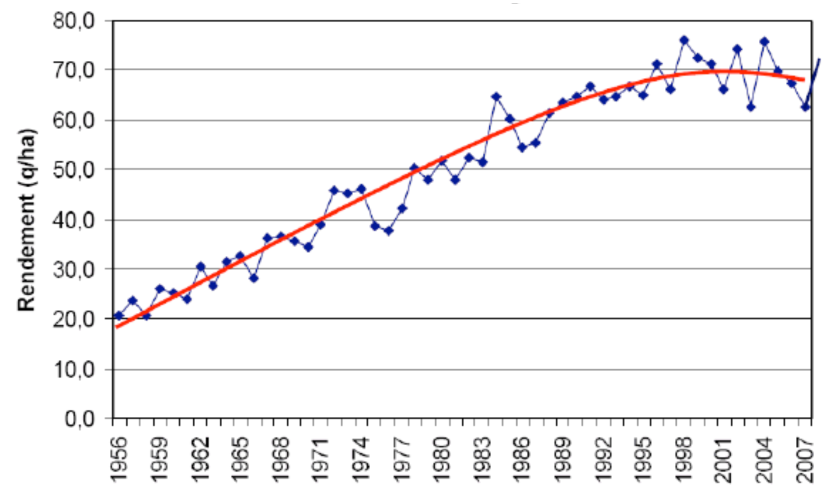
Modern wheat

Wheat yield

United Kingdom



France



Rice yield

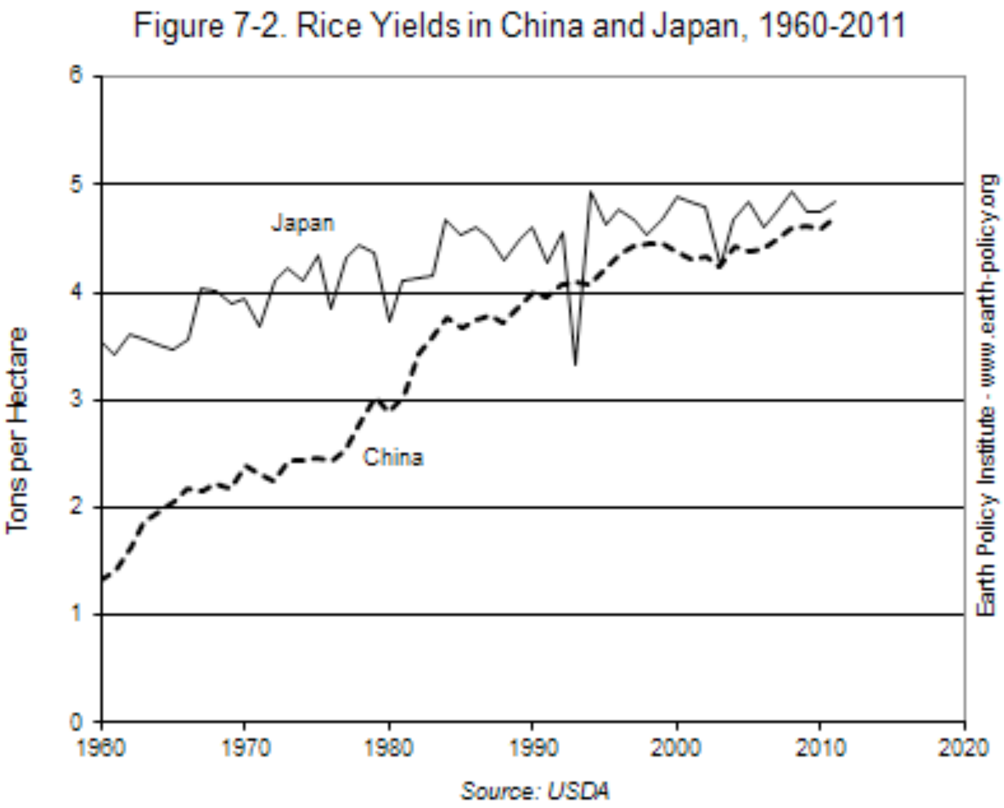
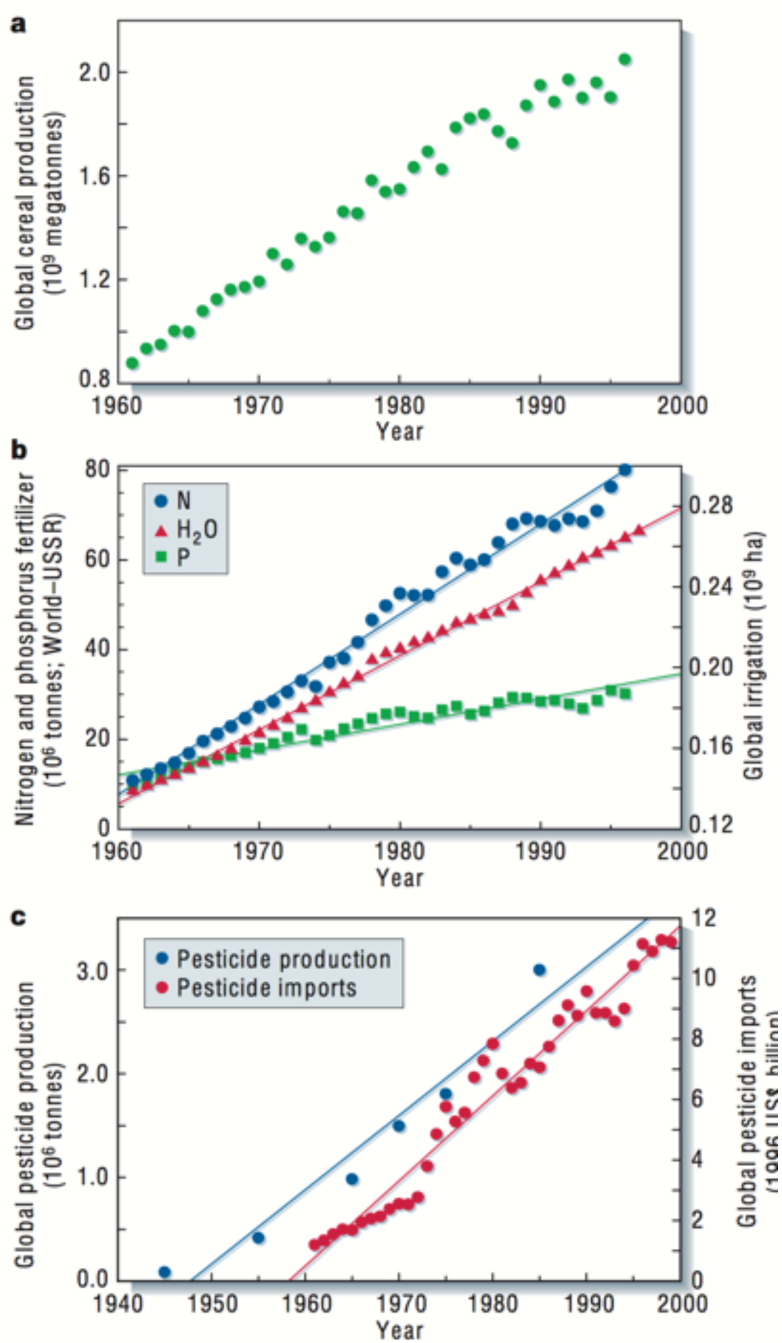


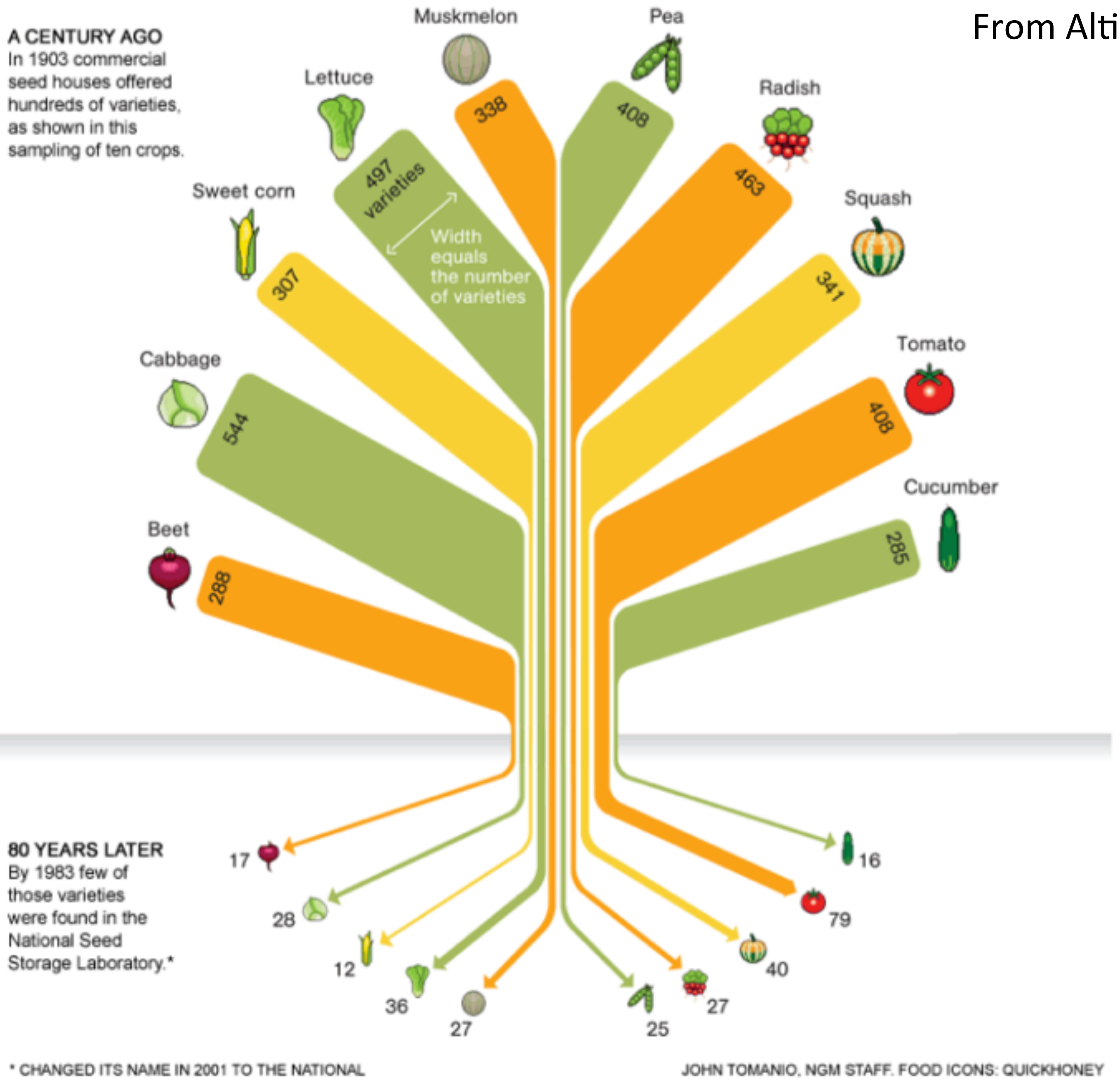
Figure 7-2. Rice Yields in China and Japan, 1960-2011
Tons per Hectare
0
1
2
3
4
5
6
1960
1970
1980
1990
2000
2010
2020
Japan
China
Source: USDA
Earth Policy Institute - www.earth-policy.org



Tilman et al 2002

Green revolution : dominant monoculture

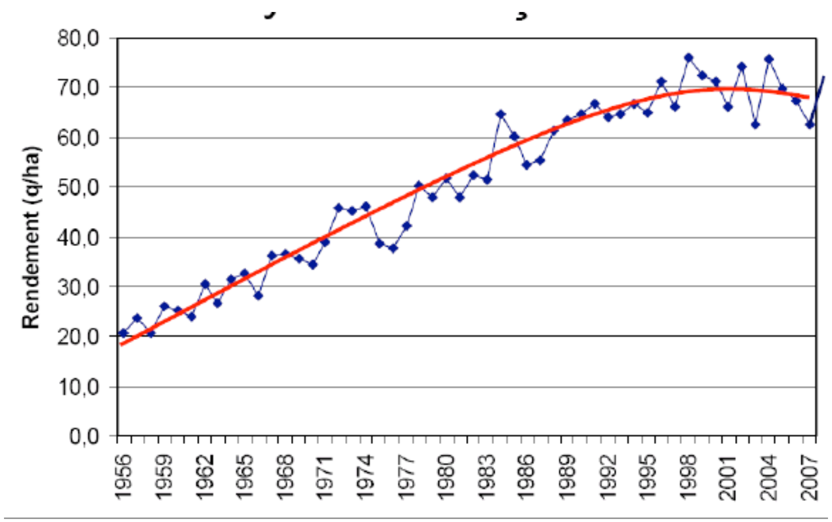
From Altieri



Less efficient

Yield/ha is currently levelling-off

Diminishing returns of fertilization



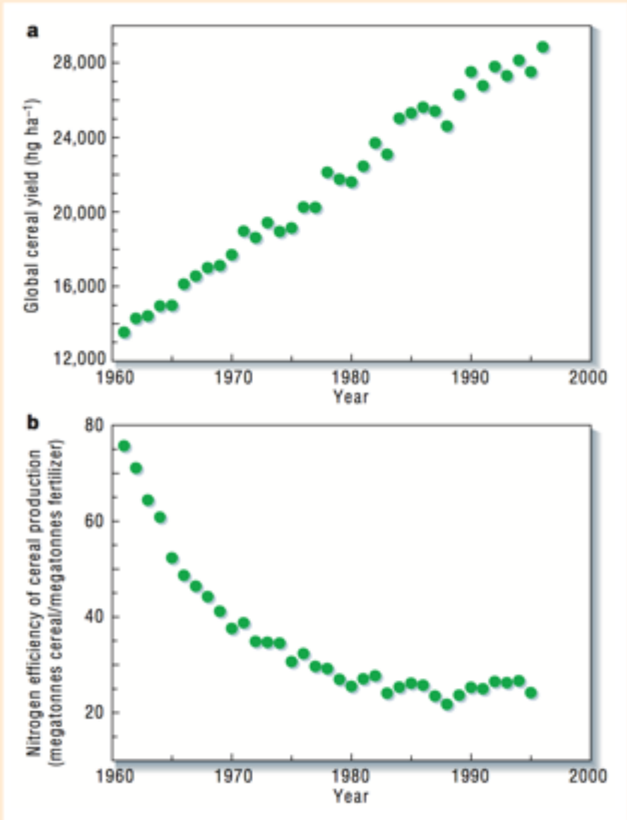


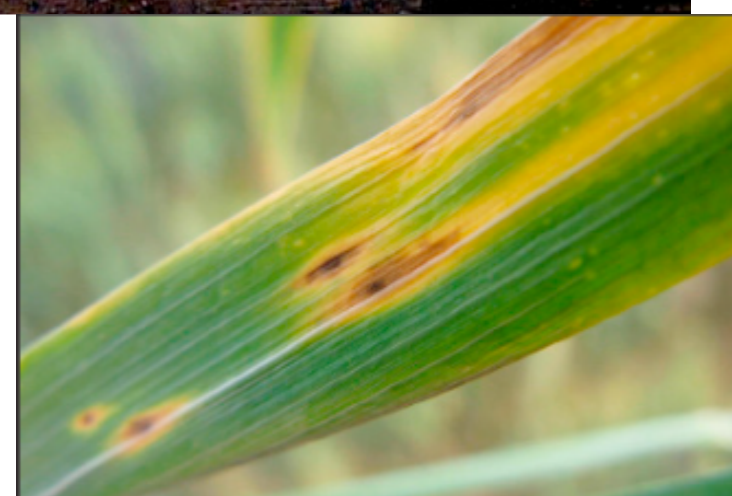
Figure 2 Diminishing returns of fertilizer application imply that further applications may not be as effective at increasing yields. **a**, Trends in average global cereal yields; **b**, trends in the nitrogen-fertilization efficiency of crop production (annual global cereal production divided by annual global application of nitrogen fertilizer)[2].

Unsustainable

Soil erosion,
drought

Unsustainable

Pests, diseases



Evolutionary perspective

Table 27.22 Past crop failures attributed to genetic uniformity

DATE	LOCATION	CROP	CAUSE AND RESULT	SOURCE
900	Central America	Maize	Anthropologists speculate that the collapse of the Classic Mayan Civilization might have been a result of a maize virus	Rhoades, 1991
1846	Ireland	Potato	Potato blight led to famine in which 1 million died and 1.5 million emigrated from their homeland	Hoyt, 1988
late 1800s	Sri Lanka	Coffee	Fungus wiped out homogenous coffee plantations on the island	Rhoades, 1991
1940s	USA		US crops lost to insects has doubled since the 1940s	Plucknett and Smith, 1986
1943	India	Rice	Brown spot disease aggravated by typhoon destroyed crop starting the 'Great Bengal Famine.'	Hoyt, 1988
1953-54	USA	Wheat	Wheat stem rust affected most of hard wheat crop	Hoyt, 1988
1960s	USA	Wheat	Stripe rust reached epidemic proportions in Pacific Northwest	Oldfield, 1984
1970	USA	Maize	Decrease in yield of 15%, $1 billion lost*	NAS 1972, Tatum, 1971
1970	Philippines & Indonesia	Rice	HYV rice attacked by leafhoppers spreading tungro virus	Hoyt, 1988
1972	USSR	Wheat	Crop badly affected by weather	Plucknett *et al.* 1987
1974-77	Indonesia	Rice	Grassy stunt virus destroyed over 3 million tonnes of rice - from the late 1960s to the late 1970s the virus plagued South and Southeast Asian rice production	Hoyt, 1988
1984	Florida	Citrus	Bacterial disease caused 135 nurseries to destroy 18 million trees	Rhoades, 1991

Notes: * Duvick (1986) reports that although the leaf blight attacked a widespread and uniform genotype, the problem was uniformity of cytoplasm - introduced to eliminate the chore of detasseling - not the genetic material in the nucleus of the seed.

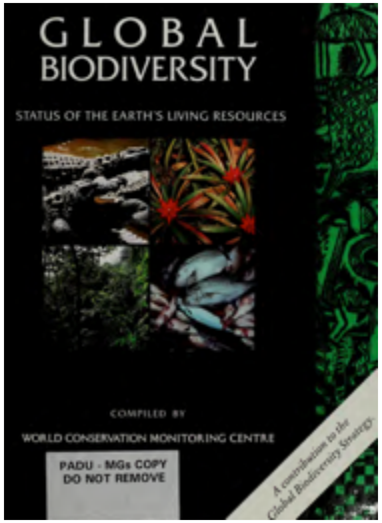


Table 35.3 Past Crop Failures Due to Genetic Uniformity

Date	Location	Crop	Effects
1846	Ireland	Potato	Potato famine
1800s	Sri Lanka	Coffee	Farms destroyed
1940s	U.S.	U.S. crops	Crop loss to insects doubled
1943	India	Rice	Great famine
1960s	U.S.	Wheat	Rust epidemic
1970	U.S.	Maize	$1 billion loss
1970	Philippines, Indonesia	Rice	Tungo virus epidemic
1974	Indonesia	Rice	3 million tons destroyed
1984	U.S. (Florida)	Citrus	18 million trees destroyed

Data from World Conservation Monitoring Centre, *Global Biodiversity: Status of the Earth's Living Resources*, Groombridge, B., Ed., Chapman & Hall, London, 1992.

Pathogens evolve to undo pest control

- Pest-resistant maize hybrids last about 4 years
- Herbicide-resistant weeds often evolve in 10-20 years
- Insecticide-resistant insects often evolve in <10 y
- Resistant strains of bacterial pathogens appear within 1–3 years

Palumbi 2001, Tilman 2002

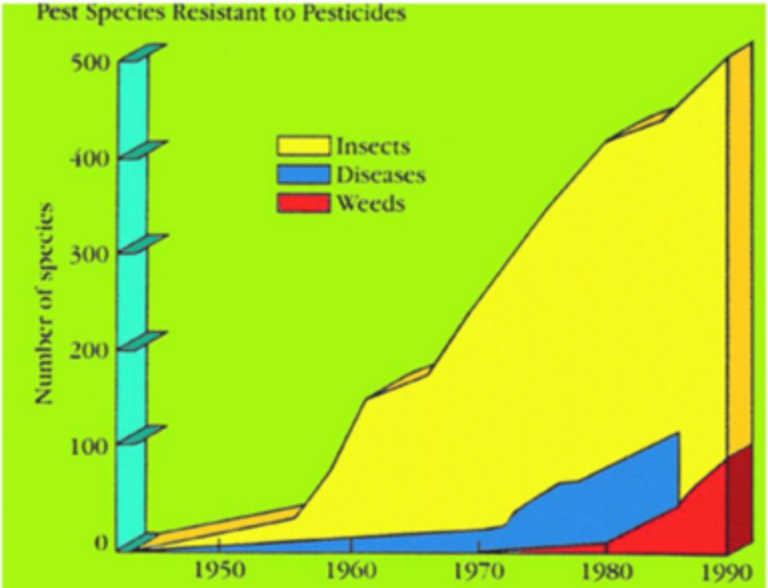
From Altieri

The futile chemical warfare against pests

- US agricultural losses to pests reached 32% between 1942-50 and 37% between 1984- 1990

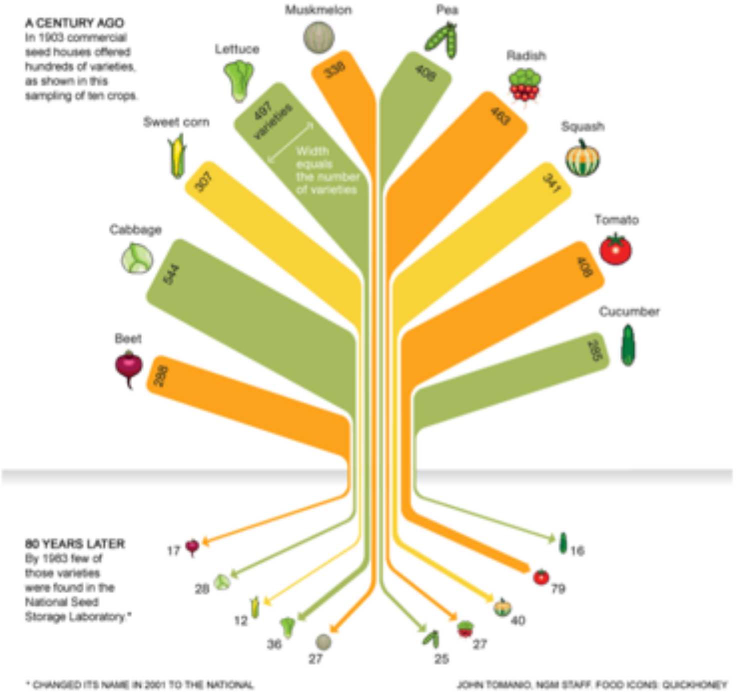
- More than 450 species of arthropods resistant to > 1000 different pesticides

From Altieri



Source: George P. Georgton, University of California, Riverside, 1990.

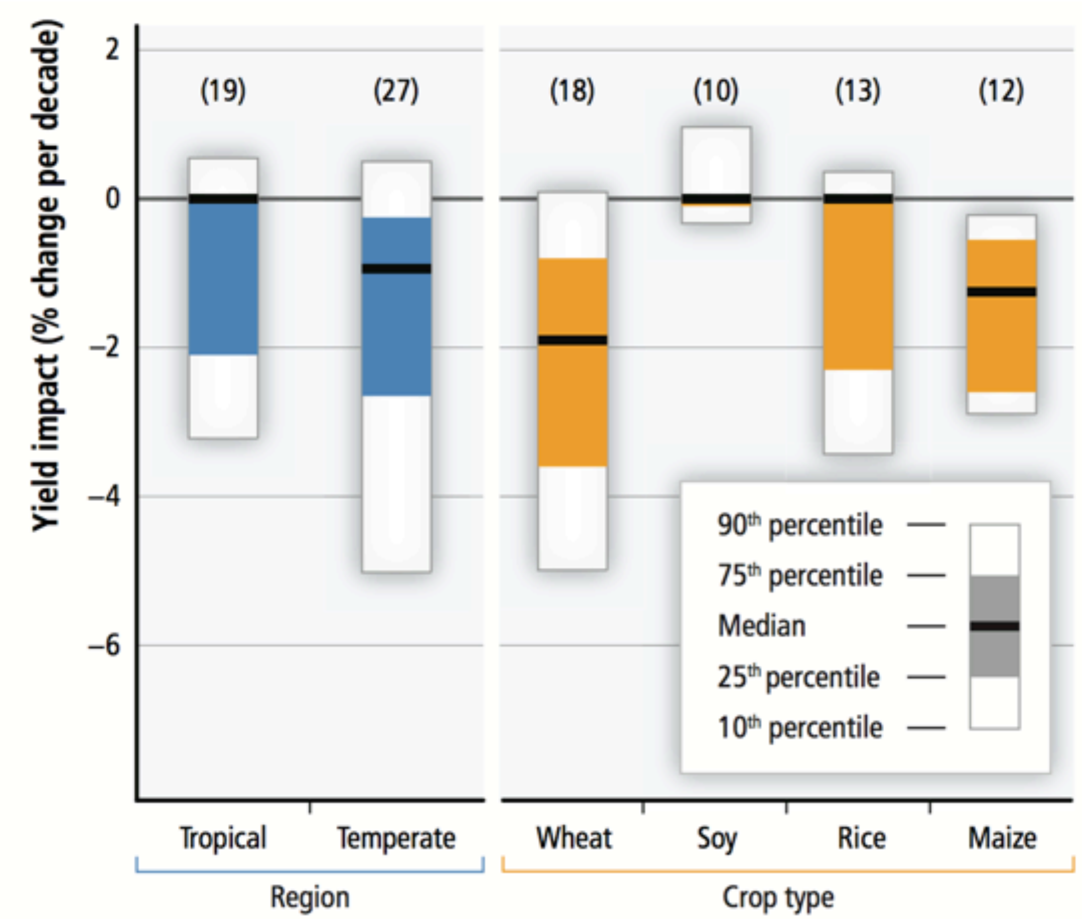
Figure 18.4 *This graph shows the number of species of insects, disease organisms, and weeds that are resistant to at least one pesticide.*



From IPPC (2014)

Response to climate change ?

Climate change



Is agriculture resilient?

- Modern agriculture may be consider to be resilient (according to some definition)
- Assuming the continued use of
  - Pesticides
  - Fertilizers
- And assuming their continued efficacy
  - Or: continued development of new pesticides

Is agriculture sustainable?

- Pollution of soil and water
- Loss of biodiversity through land-use change
- Climate change
- Dependence on phosphorus

What is needed for agricultural systems?

- Constant production despite perturbations
- Absence of epidemics
- Production without pesticides or fertilizers
- Recovery of production after climatic extreme event perturbation (flooding, drought, hurricane, etc)

Fig. 5 After Hurricane Mitch in Central America, Honduran farms under monoculture exhibited higher levels of damage in the form of mudslides (*top photo*) than neighboring biodiverse farms featuring agroforestry systems, contour farming, cover crops, etc. (*bottom photo*)

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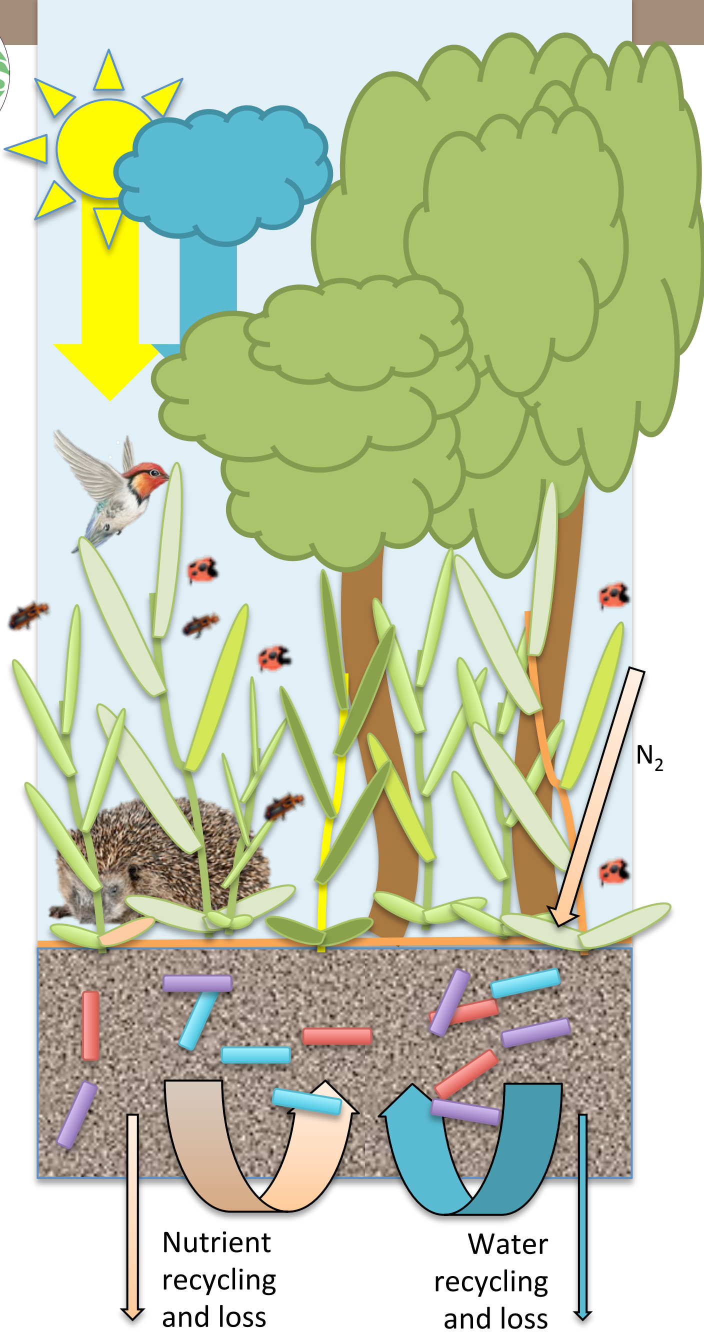
What is an agro-ecosystem?

What is an ecosystem?

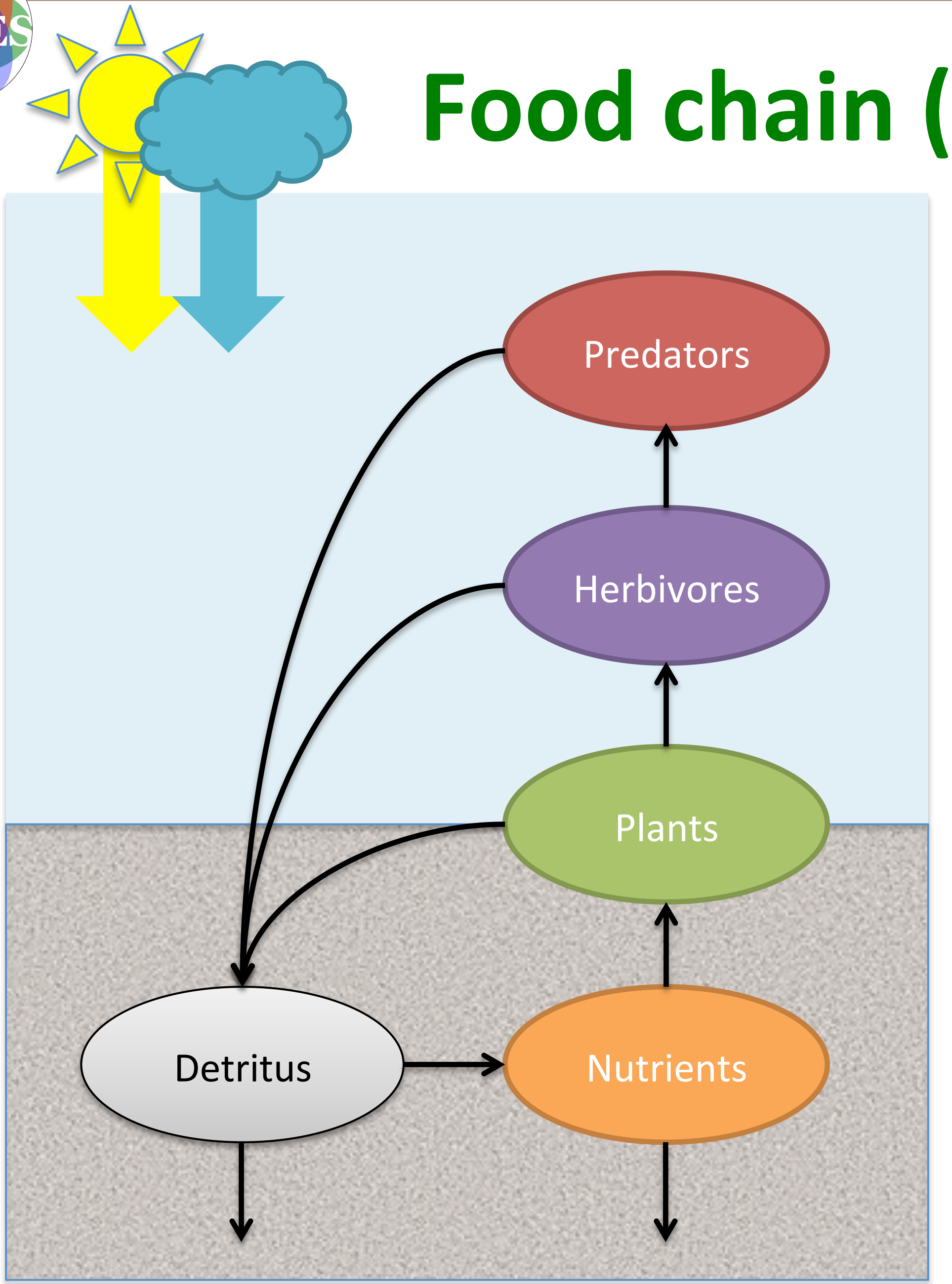
What is biodiversity?



What is an ecosystem?

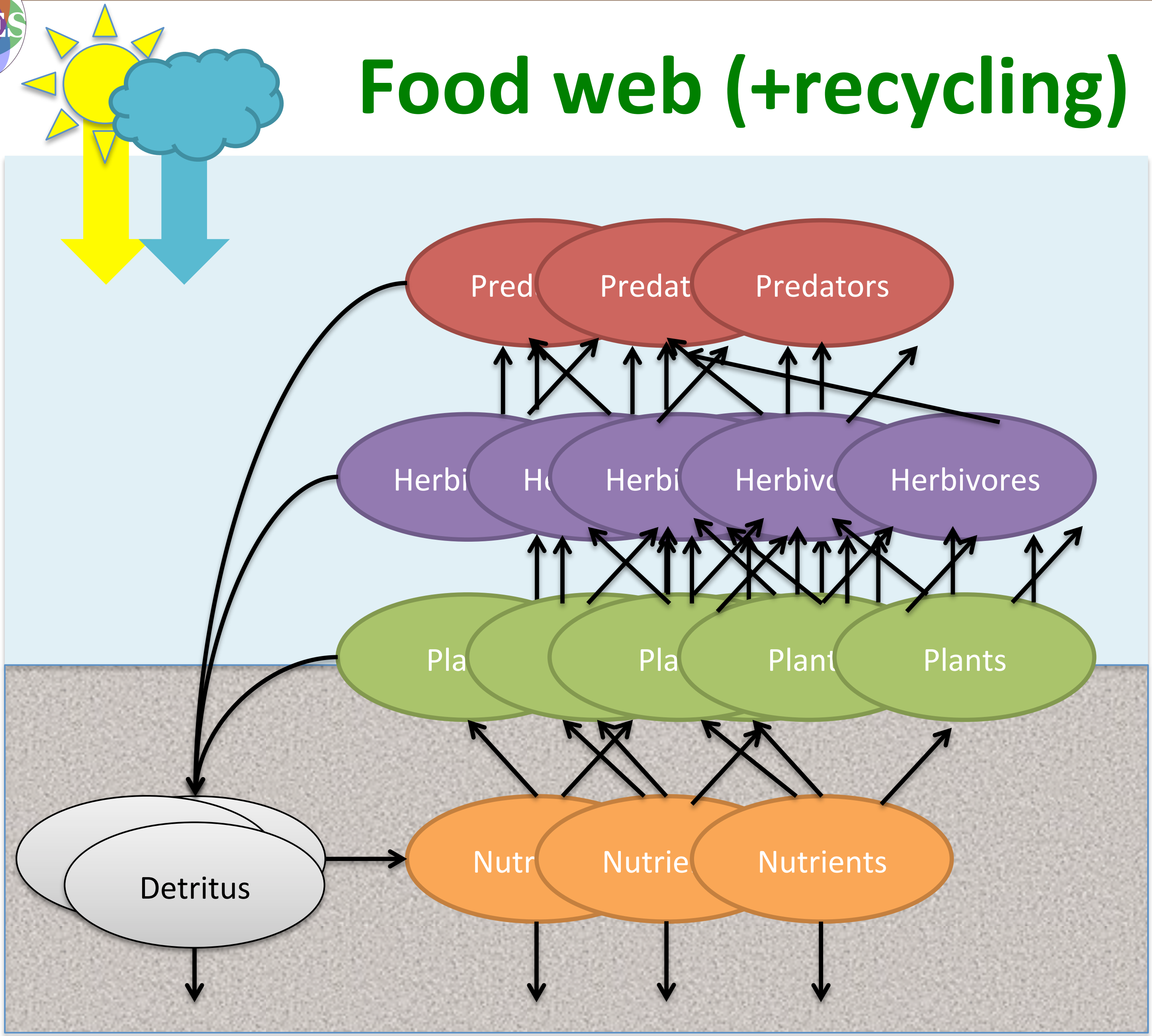
- The system of all organisms and the non-living components of their environment
  - i.e., "everything"
  - in a delimited space (lake, forest, prairie, valley, ocean…)
- In terms of
  - Energy flow
  - Matter cycling (C, N, P, …)
  - Food chain, food web: who eats whom?
  - Ecological interactions

Food chain (+recycling)



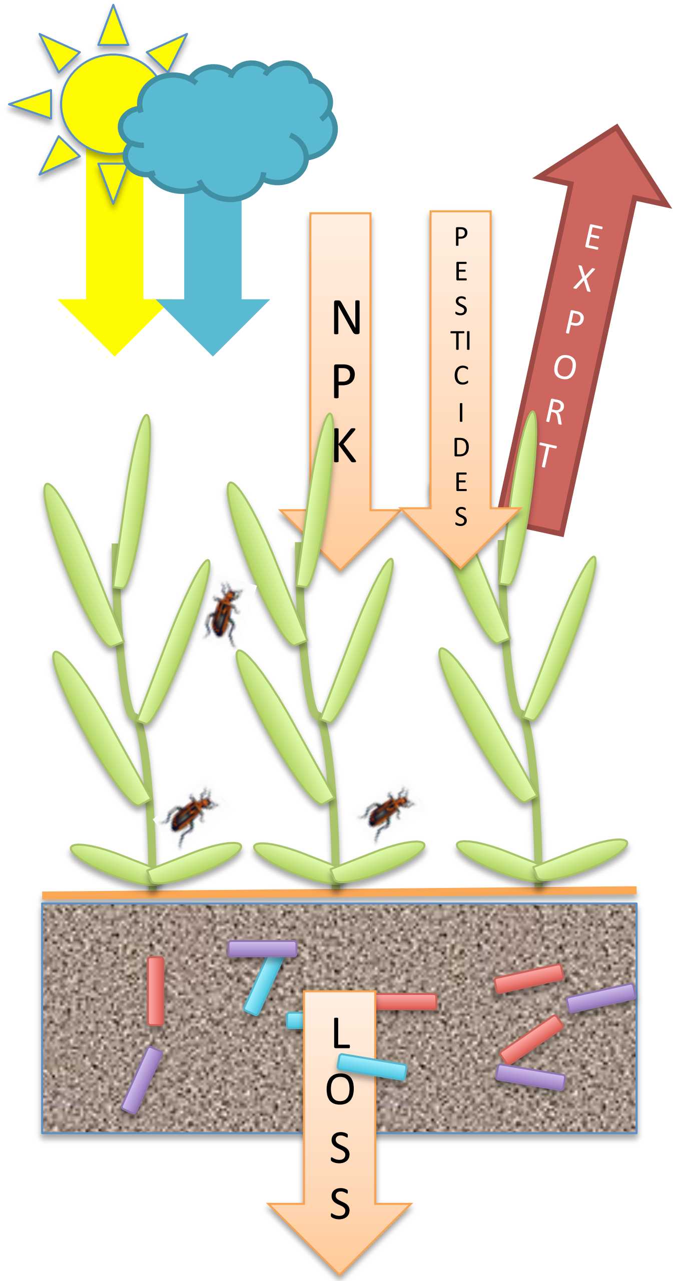
Food chain

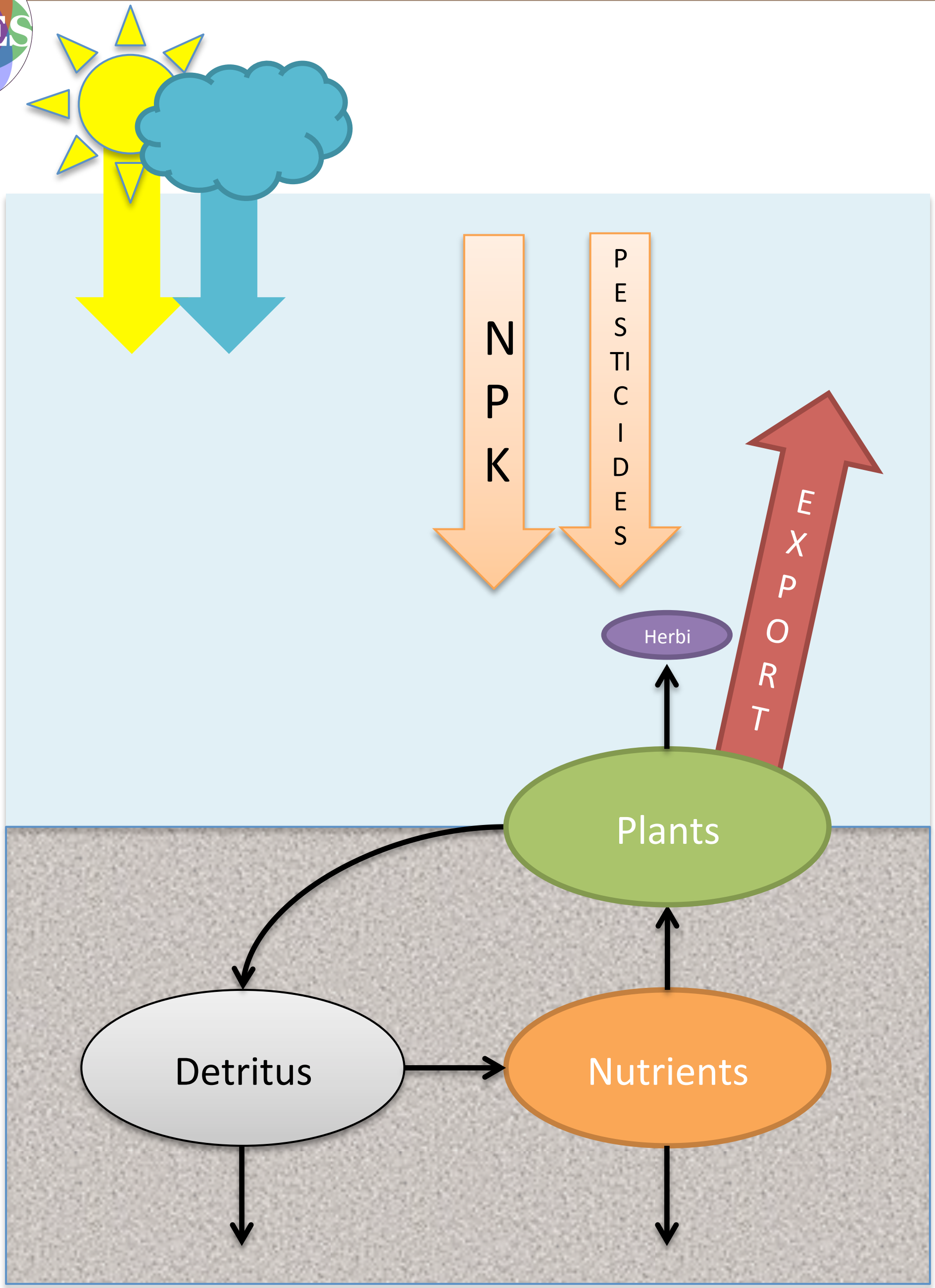
Food web (+recycling)



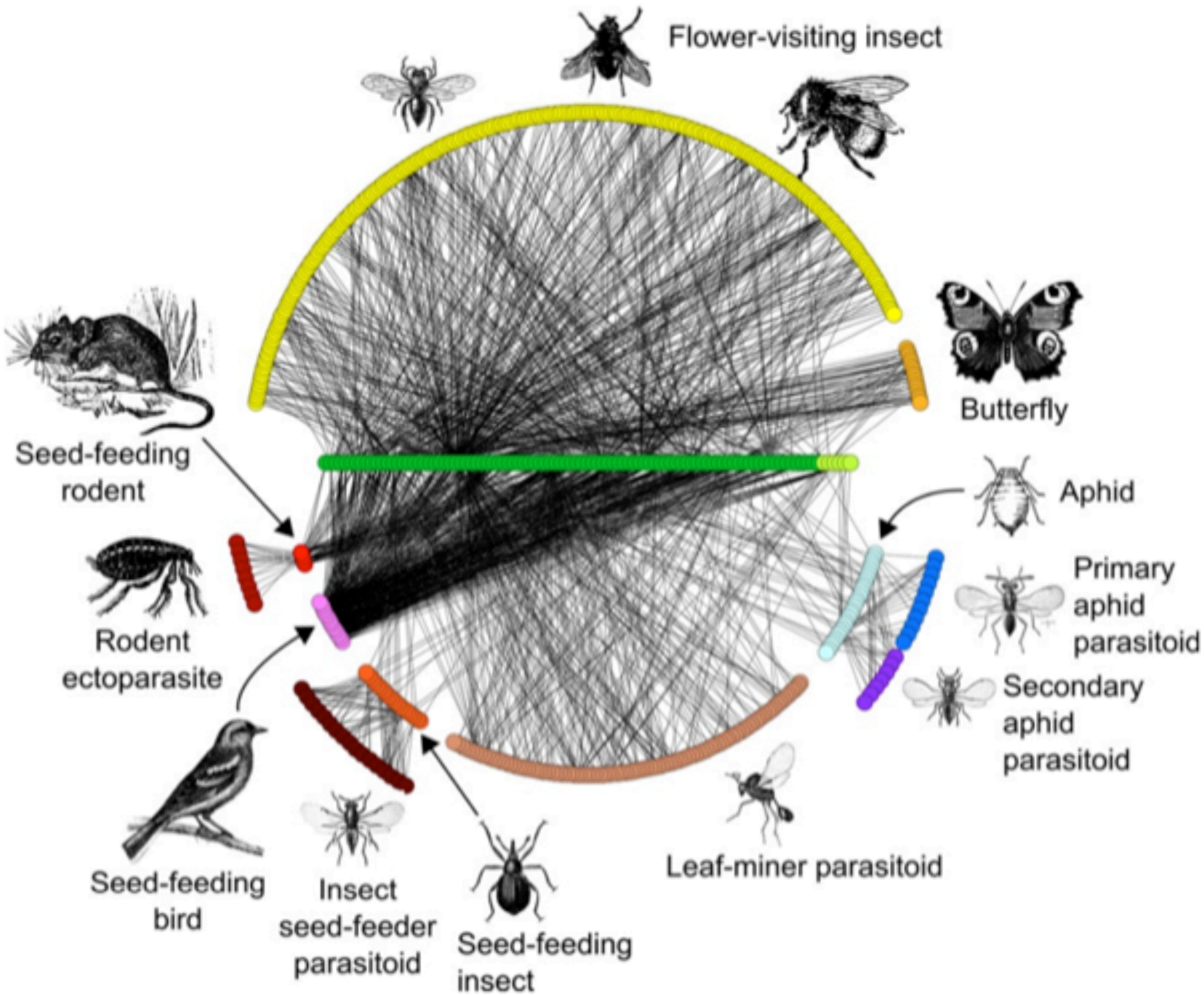
What is an agro-ecosystem?

- A simplified ecosystem
  - A single plant species: the crop
  - Genotype: artificially selected (optimized for performance under fertilization and pesticide treatments)
  - Modified environment to favor crop growth:
    - Increase nutrients (fertilization)
    - Reduce herbivores, disease and competitors (pesticides, fungicides, herbicides, plowing)
  - Harvesting: biomass export
  - Poor soil activity, high nutrient loss




N P K
PESTICIDES
EXPORT
Herbi
Plants
Detritus
Nutrients

Norwood Farm, UK (125 ha)



Pocock et al 2012

560 species
1501 interactions:
- Trophic
- Mutualistic (pollinisation)

Characteristics of natural ecosystems, traditional and modern agriculture

	Natural ecosystems	Traditional agriculture	Modern agriculture
Species richness	High	Medium	Low
On a plot scale	One ha of tropical forest contains more than 100 tree species	Most cropping systems include several plant species	Most cropping systems have a sole crop
On a global scale		Traditional agriculture is based on many species and cultivars including native species	World industrial agriculture is based on fewer than 70 species
Structure	Complex—variable	Complex	Simple—often monocanopy
Dispersion of seeds	Natural	–	Controlled
			Mechanical seed-bed preparation
Plant evolution and selection	Natural	Selection	Breeding, biotechnology
Soil cover	Permanent	Variable	Non-permanent
Simultaneous presence of perennials and non-perennials	Frequent	Frequent	Rare
Life form richness	High	Variable	Low
Productivity	Variable	Variable	High
Use of external chemicals	–	Low	High
Population control of plants and animals	Natural	Use of natural processes	Use of pesticides
Use of fossil energy	–	Low	High
Exports (C, minerals)	Low	Low	High
Nutrient sources	Recycling	Recycling, organic	Chemicals
Nutrient loss	Low	Low	High
Resilience	High	Medium	Low

Malézieux, 2012

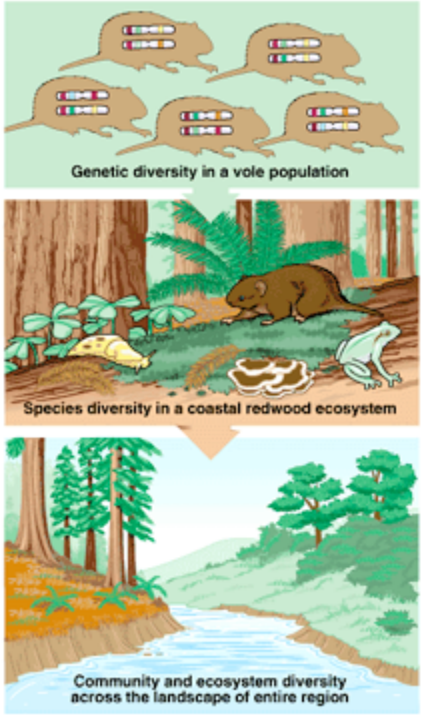
What is biodiversity?

Diversity of:

GENES

SPECIES

FUNCTIONS



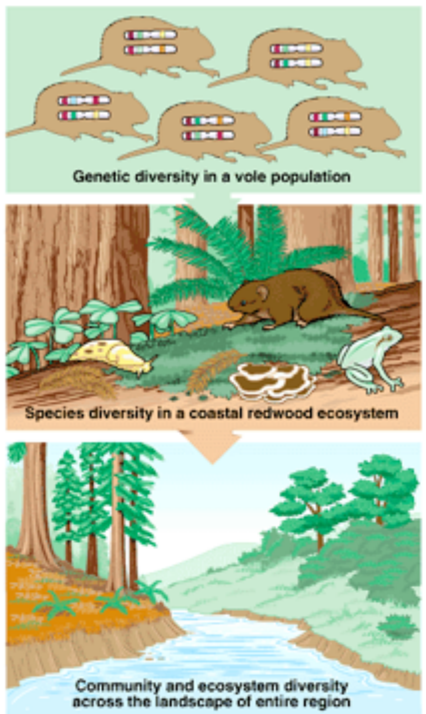
Ecosystem "functions" and "services"

Diversity of:

GENES

SPECIES

FUNCTIONS



"FUNCTIONS"

Water cycle

Nutrient cycling

Carbon sequestration

Geochemistry

Primary production

Pollinisation

Trophic interactions

Pathogen transmission

"SERVICES"

Water quality

Air quality

Climate regulation

Sol stability

Fossile energy

Natural resources

Soil fertility

Agricultural production

Resistance to invasion of exotic species

Epidemic risk

Pharmacology

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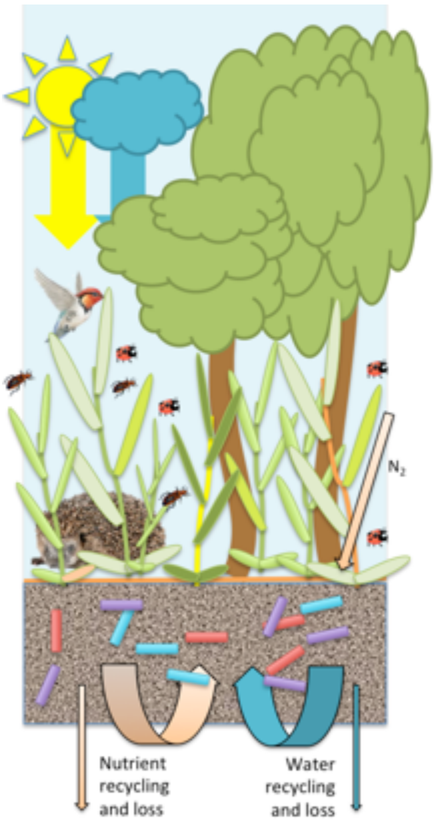
What is agroecology?

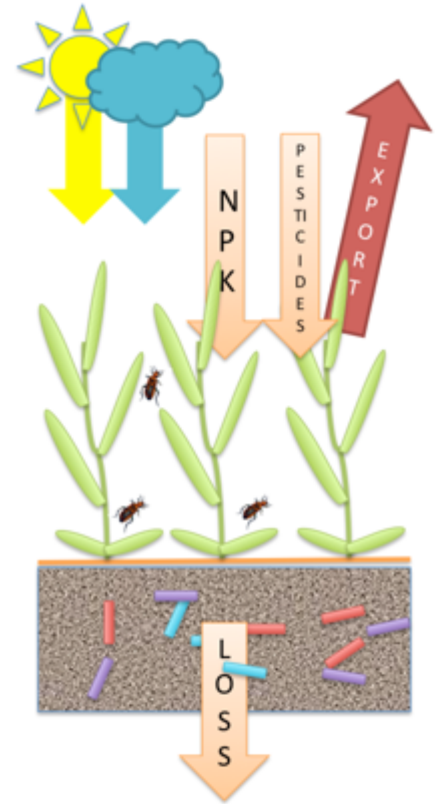
- A social movement
  - Focus on tropical countries
  - Small scale, traditional agriculture
  - Focus on social justice, role of multinationals in world inequalities, peasant independence
  - Conservation of biodiversity, cultural diversity
  - Alternative economical, societal system, human well being
- An agricultural production system
  - Us ecological processes to improve production and reduce dependence on pesticides and fertilizers
- A scientific discipline
  - How to design sustainable agricultural systems using ecological principles and knowledge?

What are the scientific principles underlying agroecology?

- Use ecological processes to improve agricultural performance while reducing environmental impact
- Biodiversity: instead of using monocultures, use mixtures of species and varieties
- Use ecological interactions between species to regulate pests
- Use ecological processes to improve soil characteristics

Natural ecosystem | "Agroecology" | Modern agriculture





Diversity, complexity, recycling, self-regulation (resilience?)

Bohan et al 2013

- Mimicry of natural ecosystems:
  - not expected to provide the yields obtained in modern agriculture,
  - Key ecological concepts in natural systems
    - resilience, stability and capacity for self-organization
  - not necessarily readily transferable or relevant to agroecosystems (Malézieux, 2011).
- Some key ecological principles should hold in agroecosystems
  - maintaining diverse complementary functional traits in species assemblages,
  - for sustaining the 'predictable' assembly of communities of species around a crop
  - for the management of the microbial, plant and animal species naturally present in the system.

Biological control

- Natural enemies of agricultural pests may be used to limit pest densities below economic thresholds (Costanza et al., 1997).
- Such regulation should allow pesticide inputs to be reduced and system resilience and sustainability to be enhanced.
- Under what conditions do we expect biological control to be effective, and in what type of network structure?

Bohan et al 2013

Common principles in agroecology

- High biodiversity (polyculture)
  - Optimal use of soil nutrients
  - Positive effect on hydrology
  - Buffer against unfavorable conditions
- Combining animal husbandry and crops
  - Fertilization
  - Weed control
  - Herbivore control
- Stimulate active, alive soils
  - Nitrogen fixation
  - Nutrient recycling
  - Favorable hydrology
- Optimize spatial organization (landscape)
  - Reduce pest and disease dispersal
  - Reduce wind damage
  - Reduce soil erosion

“Traditional” vs “Agroecological” view