Sustainability in Civil Engineering

VII. Food

Outline

- Past and present agriculture and threats to sustainability
- Alternatives
- Infrastructure/engineering approaches

1. Agriculture and Sustainability

Ecological succession

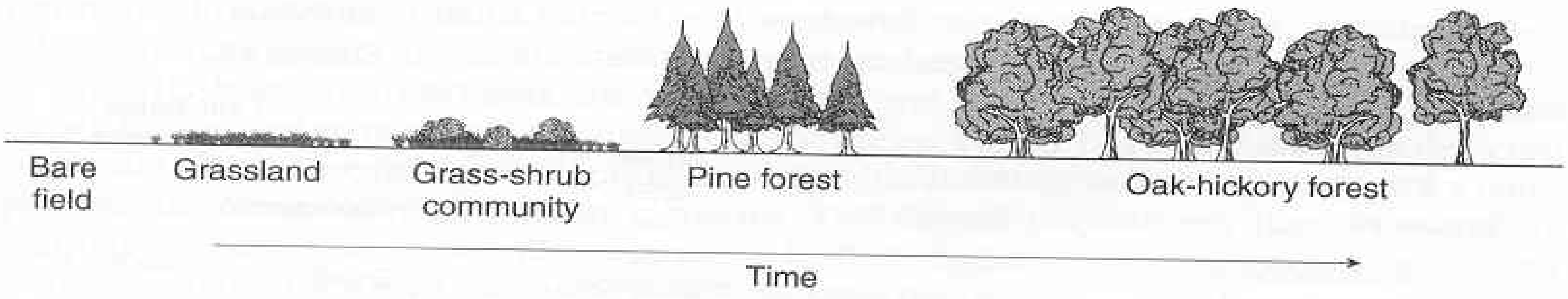
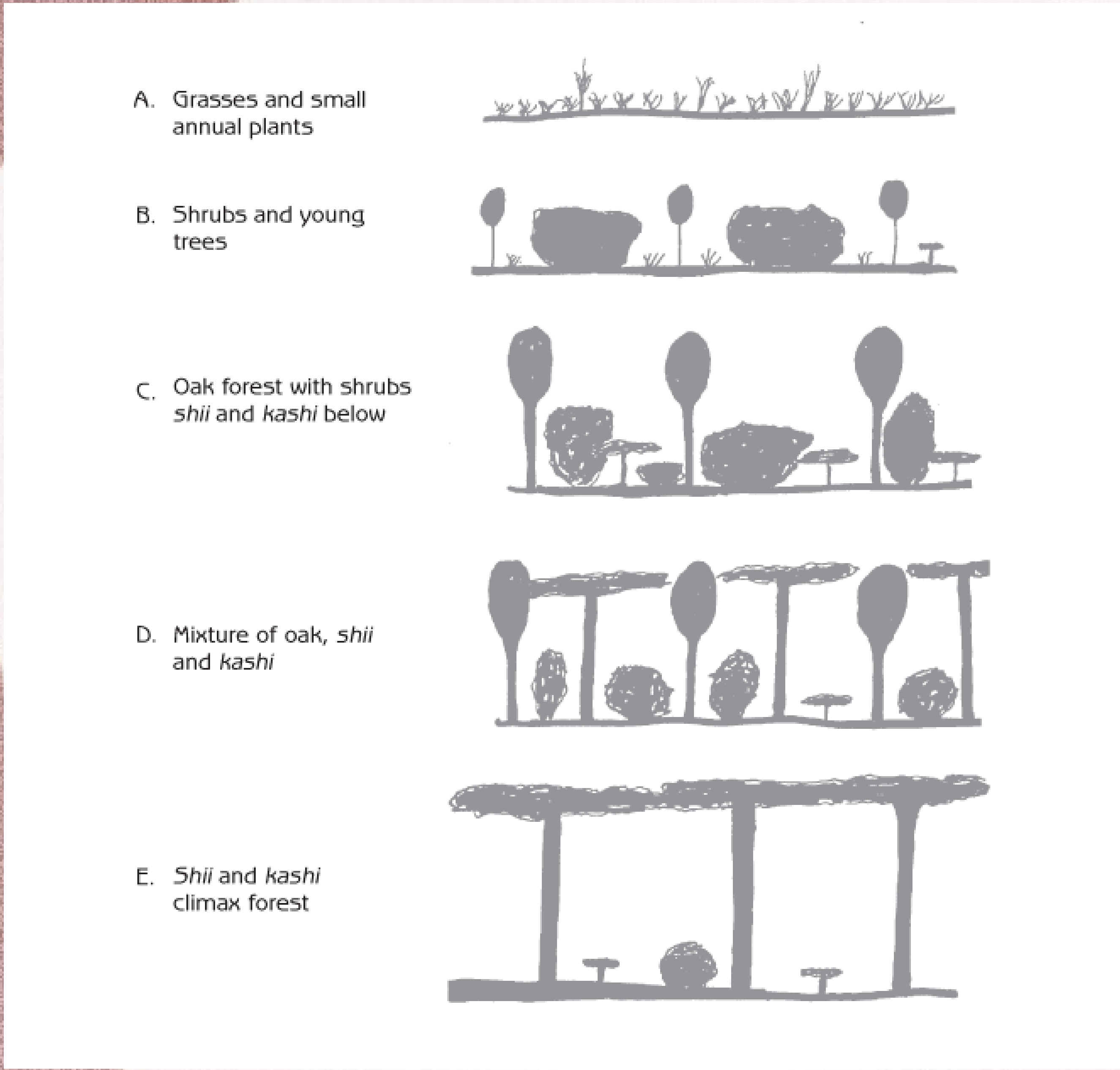


Figure 7-4 Directional changes (succession) in a community over time.

- Early-succession species: Colonizers, low diversity, fast growth, nutrient uptake, reproduction prioritized
- Late-succession species: Persisters, high diversity, slow growth, nutrient retention and recycling, maintenance prioritized

Example: Japan



Agriculture keeps fields at early succession

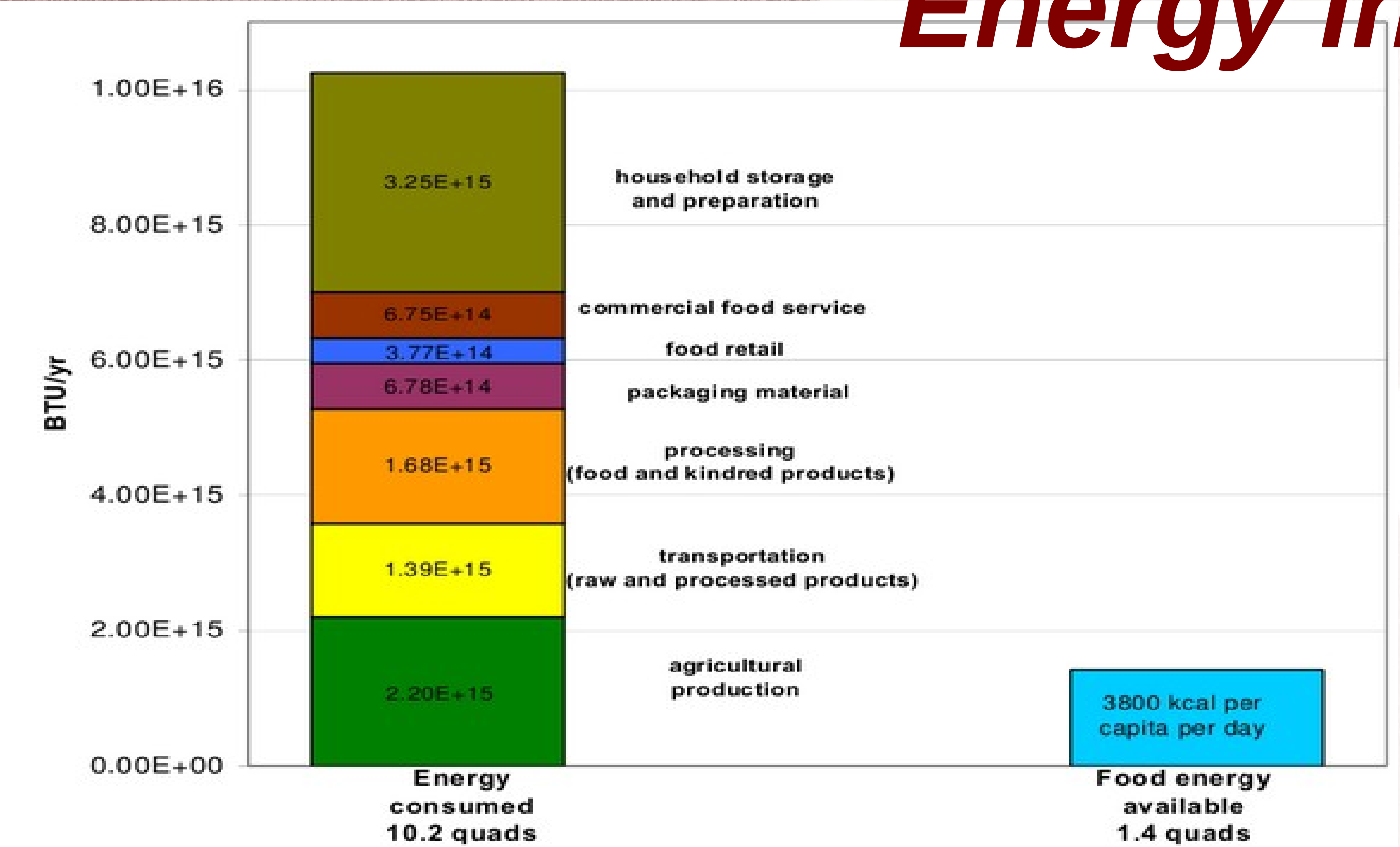
- Methods: fire, tilling, weeding
- Annual grasses etc., low diversity
- Benefits: high yields
- Costs: low nutrient and water use efficiency, niches for pests, needs continual disturbance

- Jared Diamond (1987): “Hunter-gatherers practiced the most successful and longest-lasting life style in human history. In contrast, we’re still struggling with the mess into which agriculture has tumbled us, and it’s unclear whether we can solve it.”

Trends in modern industrial agriculture

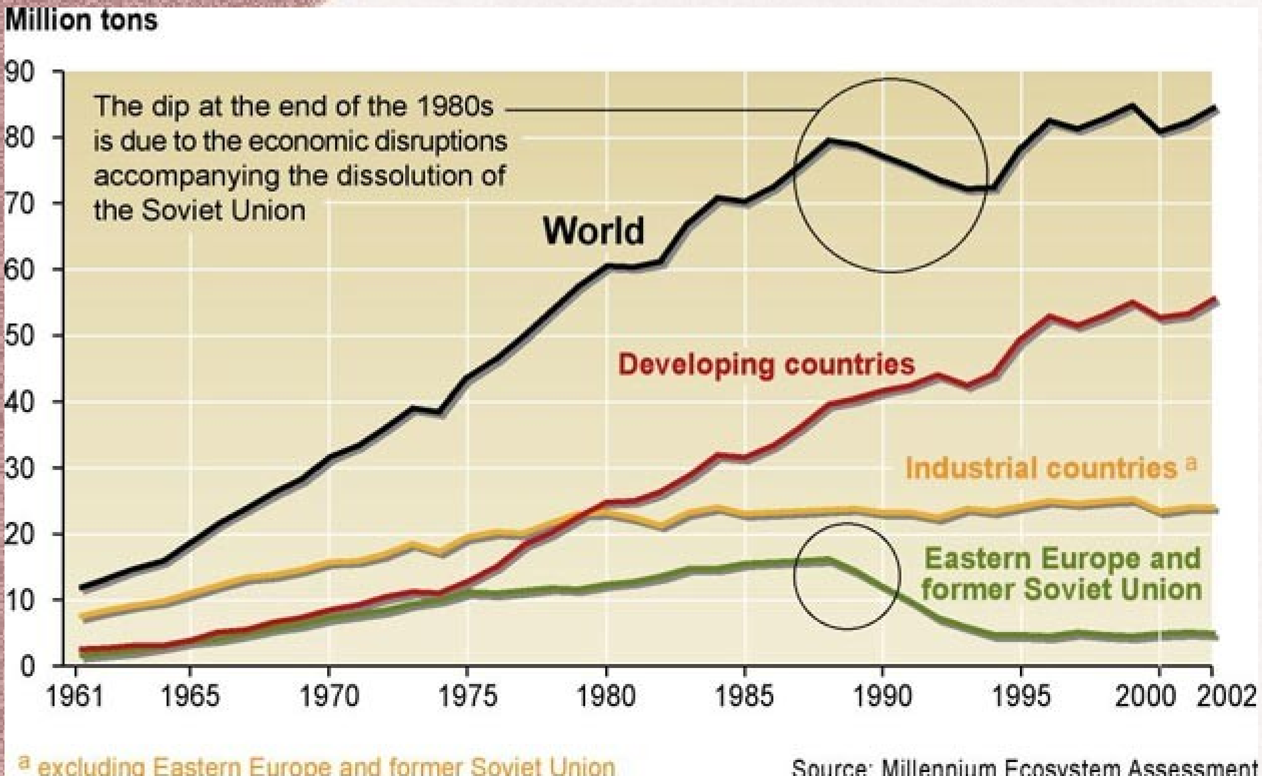
- Large monocultures
- Mechanization (lower labor inputs)
- Synthetic fertilizer to supply N, P, K, trace metals
- Herbicides and pesticides
- Hybridized or genetically engineered, uniform (centrally generated) seeds
- Result: large harvests of a few crops, most of which are processed or fed to animals
- High yields from unsustainable extraction of fossil fuels, soil, water, phosphate rock

Energy in agriculture



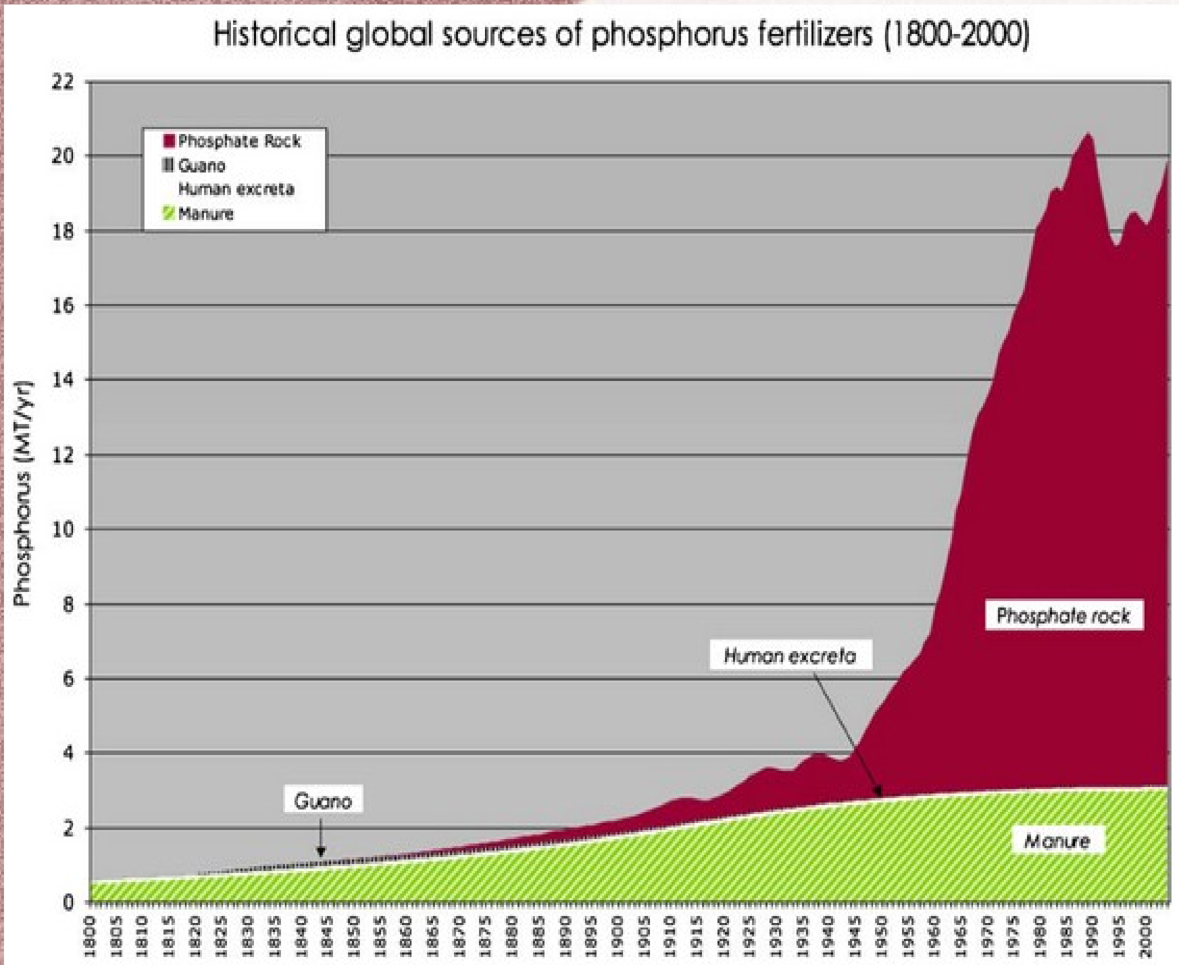
- Without fossil fuels, agriculture has the role of collecting solar exergy (several units of food exergy out per unit of labor exergy put in)
- The fossil-fuel exergy put in to USA agriculture is comparable to the food yield (20% of farm expenses, more than labor); adding the rest of the food sector makes the picture much worse (see above)

Fertilizer: N



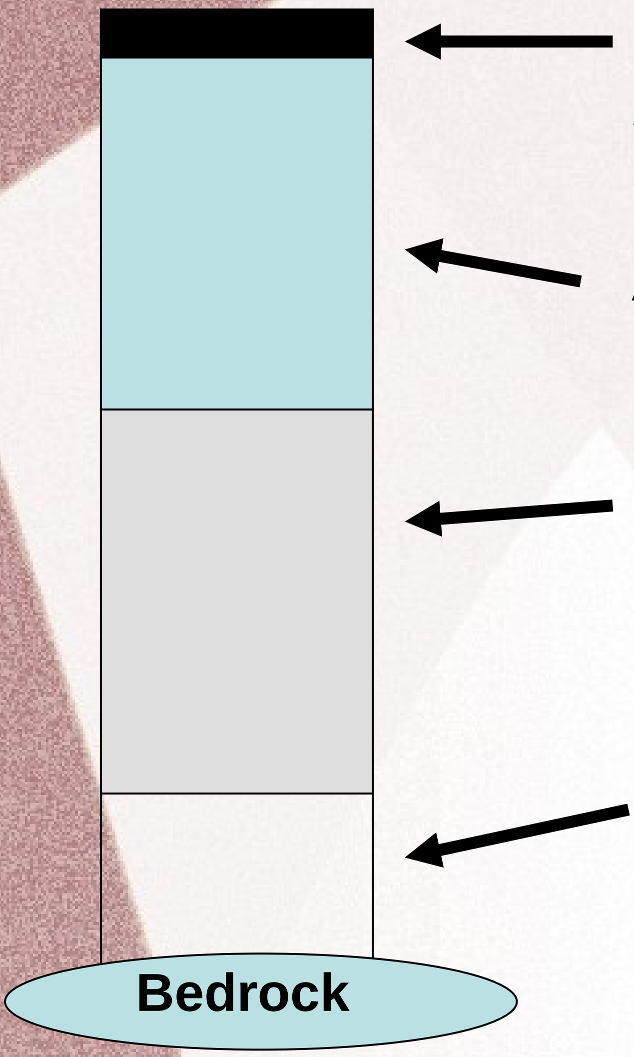
- Nitrogen is fixed naturally by lightning and specialized soil or legume-root bacteria
- Haber process: fix N using natural gas as a reducing agent – more than doubled fixation rate (uses 5% natural gas prod.)

Fertilizer: P



- Phosphate is not found in atmosphere, recycled in natural ecosystems and traditional agriculture
- In recent decades, reliant on rare concentrated phosphate minerals

Soil



O horizon – contains litter on surface, humus + OM beneath

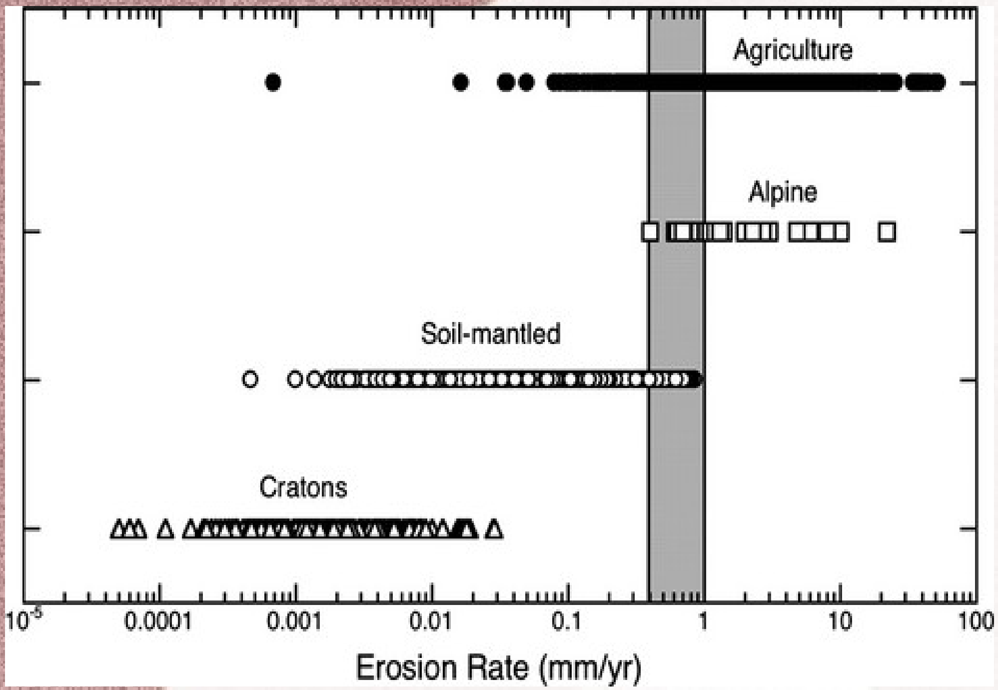
A horizon – various stages of breakdown of organic matter

B horizon – mineral soil in which organic compounds have been converted into inorganic

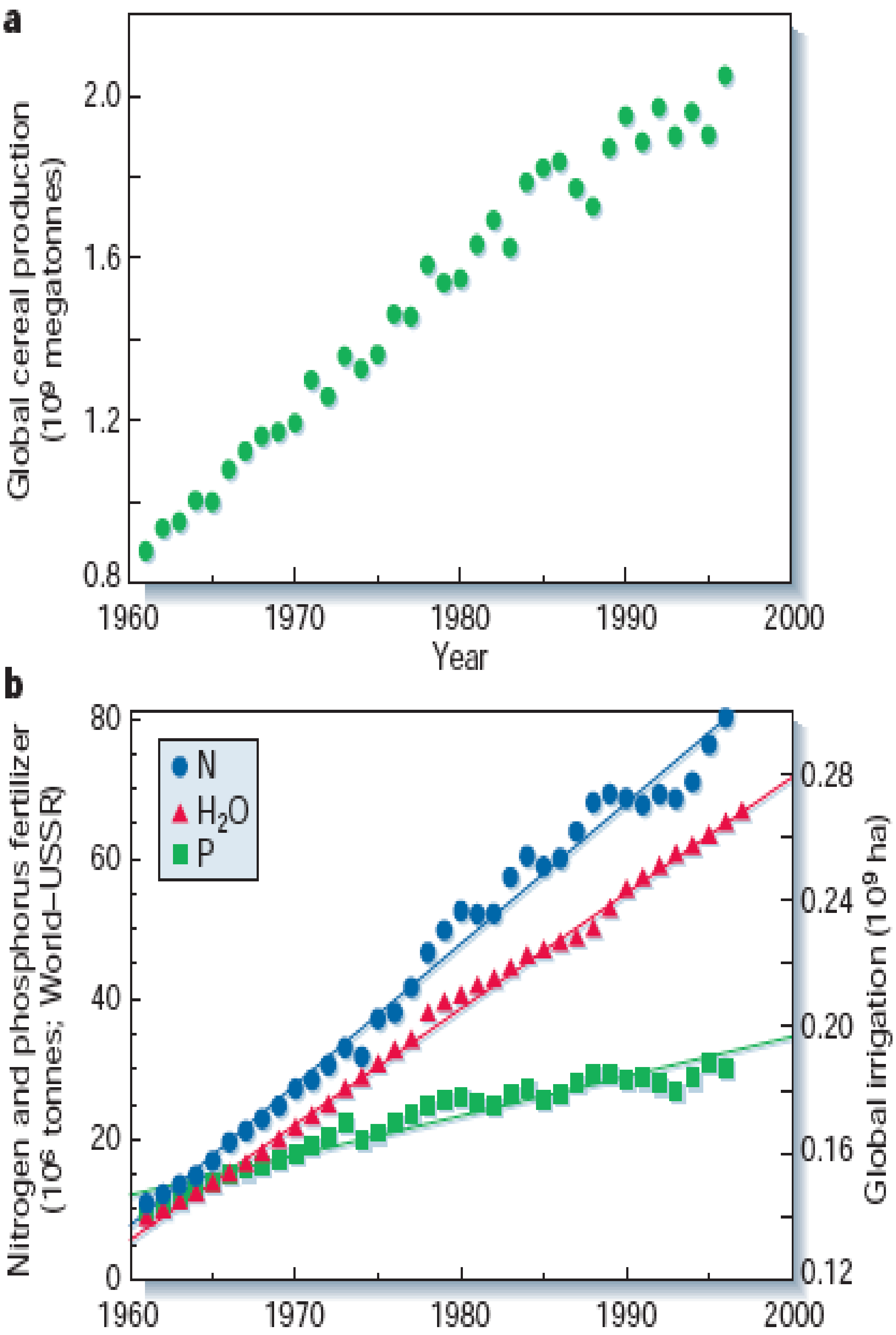
C horizon – unmodified parent material

Created by and nourishes plant cover;
stores water and nutrients

Soil erosion



- Plowing compacts soil, making it harder for plants to access water and nutrients
- Plowing and planting annual plants leaves bare soil much of the time; it can be carried away by rain and wind (Dust Bowl), and nutrients lost faster



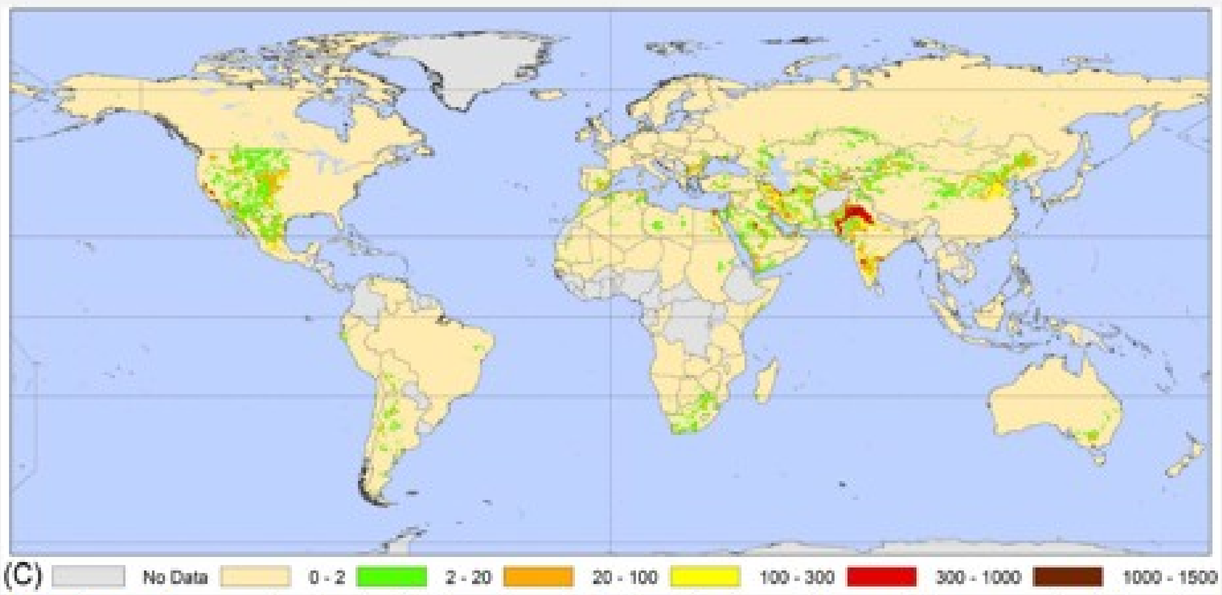
Water

- In most grain-growing areas, high yields require irrigation for dependable water
- 70% of world water use
- Cf. 2010: Russia bans wheat exports after 25% of crop lost in drought

Groundwater depletion

Dangerous dependence on virtual water deepens

23 September 2010 | Author: koneil



Global map of groundwater depletion, where 1000 on the legend is equal to one cubic kilometer of depletion per year. Courtesy: Marc Bierkens (*Correction)

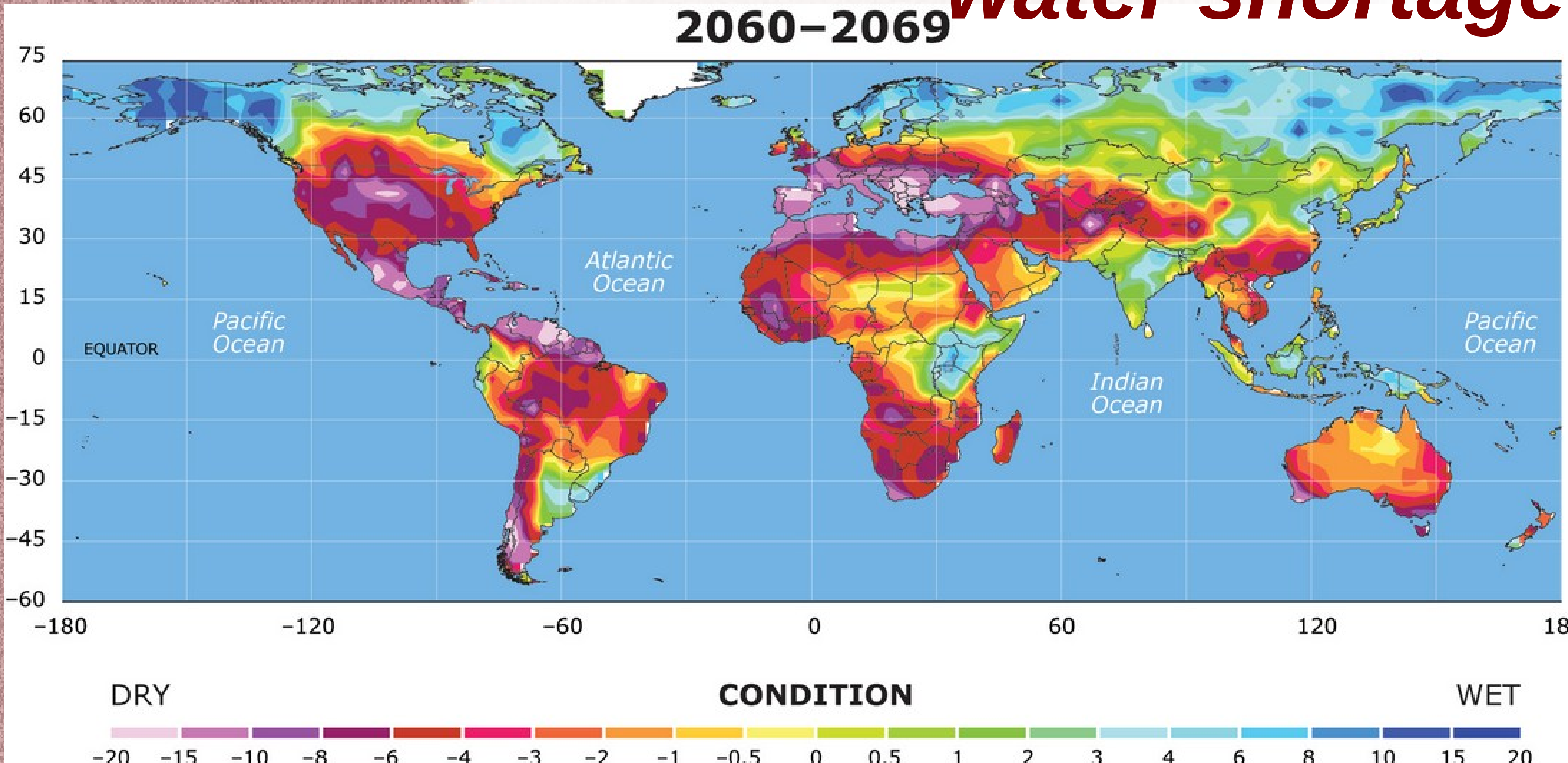
Research Blogging

The rate of global groundwater depletion has been on the rise, warning of a potential disaster for an increasingly globalized agricultural system says Marc Bierkens of Utrecht University in Utrecht, the Netherlands.

In an upcoming study, Bierkens and his colleagues find that not only is global groundwater extraction outstripping its natural recharge rate, this disparity has been increasing.

Groundwater represents about 30 percent of the available fresh water on the planet, with surface water accounting for only one percent. The rest of the potable, agriculture friendly supply is locked up in glaciers or the polar ice caps. This means that any reduction in the availability of groundwater supplies could have profound effects for a growing human population.

Global warming will likely worsen water shortage



Modeled mean Palmer Drought Stress Index:

<0: dryer than 20th-century conditions,

<-3: extreme drought by 20th century standards

Heat stress on plants

- Crop yields start to decrease rapidly somewhere between 90 ° and 110 °F, depending on the species, variety, and growth stage, even with plenty of water

“Corn was originally a tropical grass from the high elevation areas of central Mexico about 7,400 feet above sea level, 2,000 feet higher than Denver. Today, corn still prefers conditions typical of that area — warm daytime temperatures and cool nights. Areas that consistently produce high corn yields share some significant characteristics. These areas — central Chile, the west slope of Colorado, etc. — are usually very bright, clear, high light intensity areas with cool nights.

Corn maximizes its growth rate at 86°F. Days with temperatures hotter than that cause stress. In the high yield areas, cool night temperatures — at or below 50°F — reduce respiration rates and preserve plant sugars, which can be used for growth or reproduction, or stored for yield.

This year [2011], in the prairie states and in the Corn Belt, conditions have been dramatically less than optimal.”

Pest control

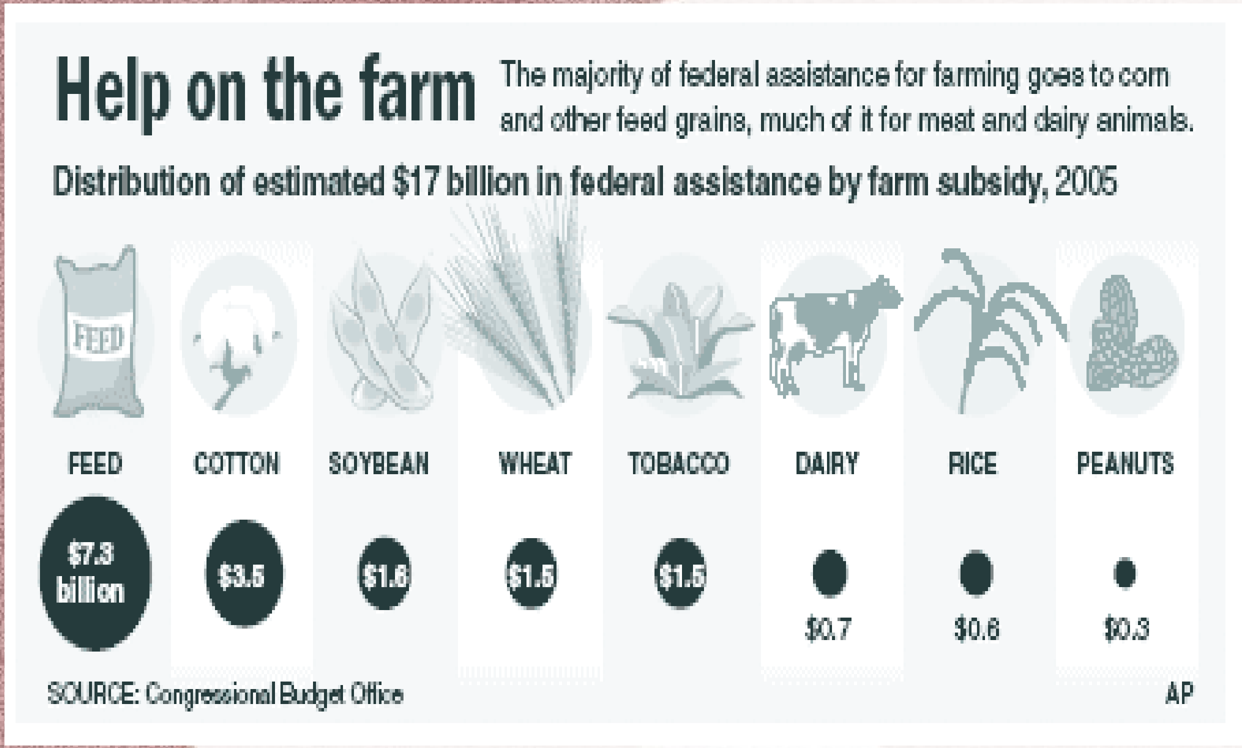
- Low-diversity, high-input fields offer rich opportunities for specialized herbivores
- Chemical pesticides have been widely used against weeds and insects since WWII, with harm to farmers, amphibians, bees
- "Ironically, it appears that the losses due to pests are still increasing, despite the availability and widespread use of chemical pesticides." (World Bank) – pests evolve to resist applied chemicals

	Rice	Wheat	Maize	Corn	Coffee	Potatoes
Pathogens	3.3	1.4	7.8	4.3	2.8	9.8
Insects	45.2	10.5	10.4	6.3	2.8	9.6
Weeds	43.2	14	9.3	4.9	2	5.3
Total	112.5	38.5	27.4	15.5	7.6	24.8

Source: modified from Oerke *et al.* 1995

Table: estimated losses ($billion / year); ~42% reduction in yield

Government intervention



- Farm subsidies have helped rehabilitate from Dust Bowl, averted price collapses (school lunches, food aid), but promote monoculture and industrial practices
- Primarily welfare for agribusiness

Industrial agriculture is unsustainable at multiple levels

	Economic	Social	Environmental
Production	– Rapid conversion of prime farmland – 84% of farm household income earned off-farm – Increasing number of farms report a net loss (48% in 1997)	– 52% of farmworkers are illegal – age of farm operators increasing; declining entry of young farmers	– depletion of topsoil exceeds regeneration – rate of groundwater withdrawal exceeding recharge in major agricultural regions – losses to pests increasing – reduction in genetic diversity
Consumption	– Costs of diet related diseases increasing	– Obesity rates rising – Diet deviates from nutritional recommendations	– 26% edible food wasted
Total system	– Marketing is 80% of food bill – Industry consolidation in food system threatens market competition	– Relation with food and its origin has been lost	– Heavy reliance on fossil energy – 7.3 units of energy consumed to produce one unit of food energy

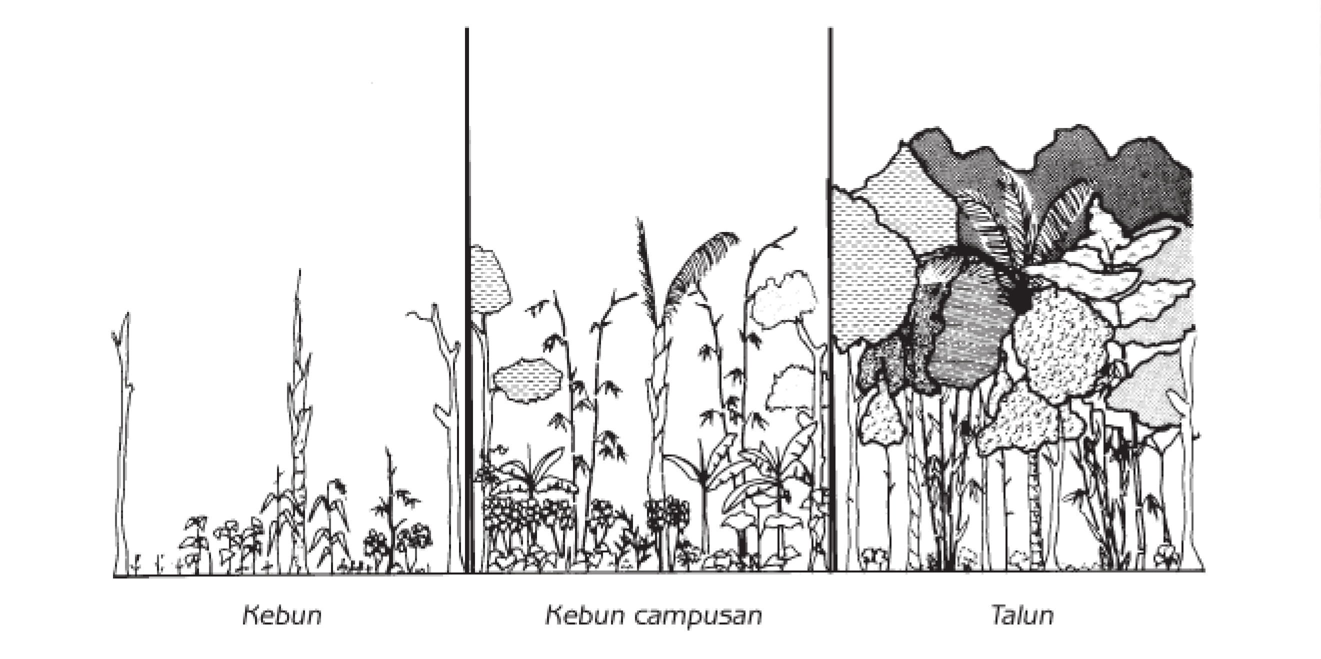
Martin C. Heller and Gregory A. Keoleian, *Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System* (2000)

2. Alternatives

Toward sustainable food

- Need to address many levels: for example, organic food eliminates mined fertilizer exergy and pollution while local food reduces transportation exergy, but these are only a minority of total food-system exergy use
- Grain-fed meat/milk multiplies the negative impact of industrial agriculture
- Should consider food security and resilience across political, resource, and climate conditions

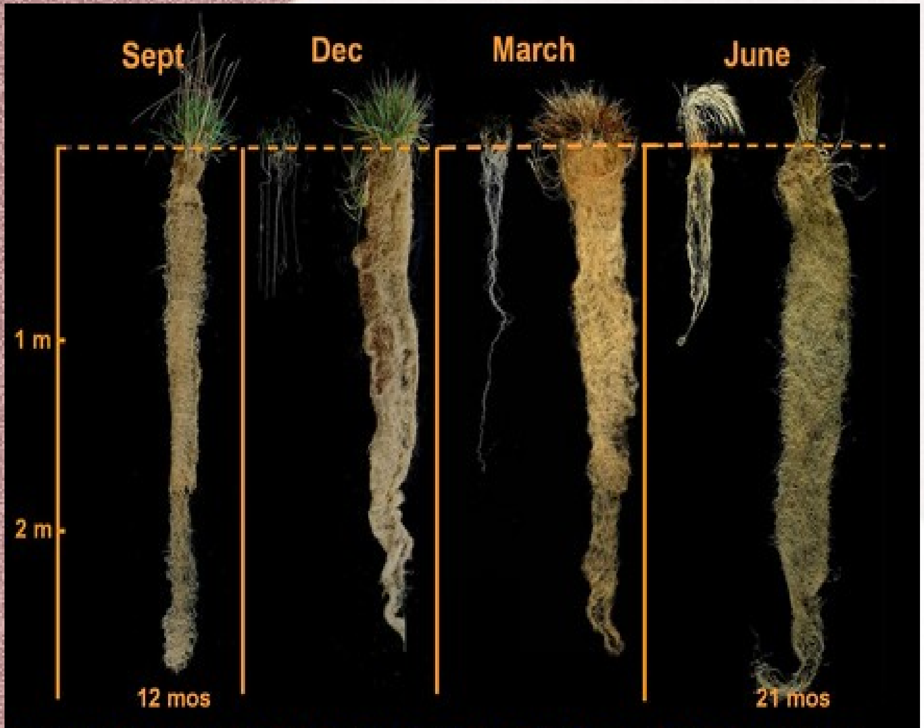
Polyculture and agroforestry



Succession of a Javanese polyculture field from domination by annual field crops to domination by tree crops; Christanty et al. (1986) 'Traditional agroforestry in West Java: The pekerangan (homegarden) and kebun - talun (annual - perennial rotation) cropping systems' in Marten, G, *Traditional Agriculture in Southeast Asia: A Human Ecology Perspective*

- Planting multiple crops together: more resilience to climate, resistance to pests, build and retain soil
- Long-term polyculture can use ecological succession to yield a variety of products

Perennial grasses?



Annual wheat (on left in each panel) and Perennial wheatgrass

- Grains are annual grasses bred to have big seeds – need to be planted each year on empty fields and kept from weeds
- Perennials devote less energy to reproduction (seeds) and more to roots; the Land Institute and others aim to hybridize them with annuals to achieve acceptable yields

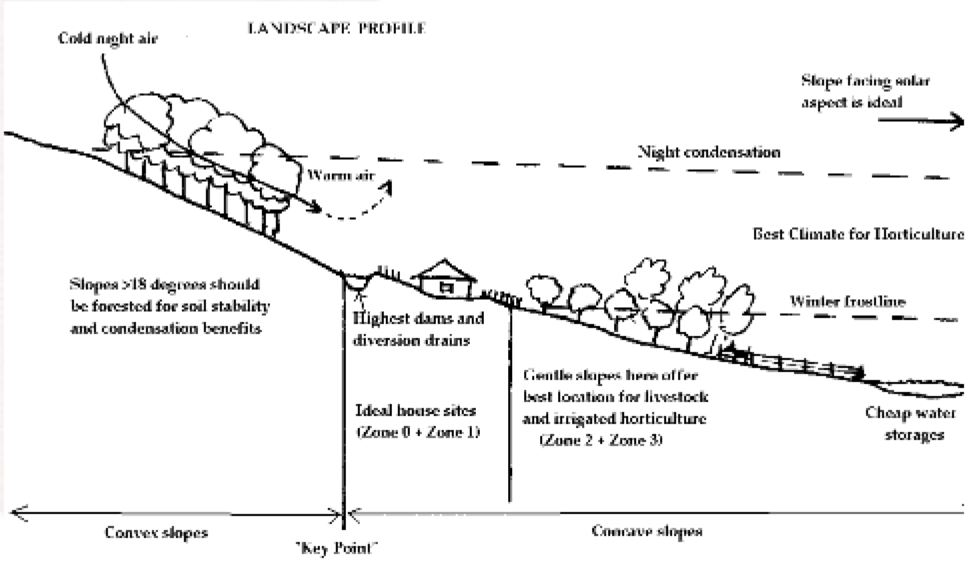
Bison: real free-range meat

- Replace millions of grass and corn-fed cattle with similar numbers of bison in the Great Plains
- Perhaps the only extensive sustainable food use for center of country, in terms of water supply

"We are suggesting that the region be returned to its original pre-white state, that it be, in effect, deprivatized." (D. and F. J. Popper, "The Great Plains: From Dust to Dust – A daring proposal for dealing with an inevitable disaster", *Planning* magazine [1987])

3. Civil Engineering in Sustainable Agriculture

Landscape design for ecoagriculture

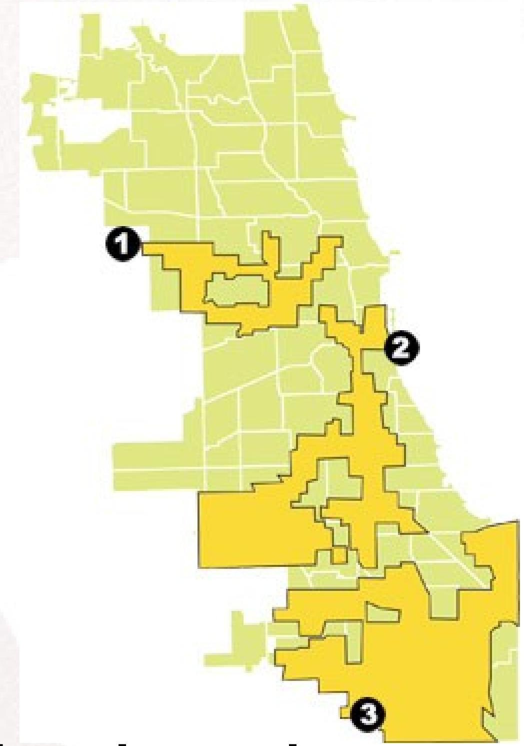


Beneficially use local exergy flows (how?)

A checklist of food impacts of building

- Is farmland being lost (that distant/marginal land might be cleared to replace)?
- Will pollution from the site (e.g. stormwater runoff) contaminate farming?
- Is there a supply for nutritious food for residents?
- Are there opportunities to build food into the project (e.g. edible landscaping, aquatic life)?

Food deserts



- Both rural areas and poor urban neighborhoods may not be well supplied with fresh food because they are not perceived as a promising market
- Being addressed both thru local food production (e.g. NYCCGC) and supply arrangements (e.g. GrowNYC food boxes, FRESH tax incentives)

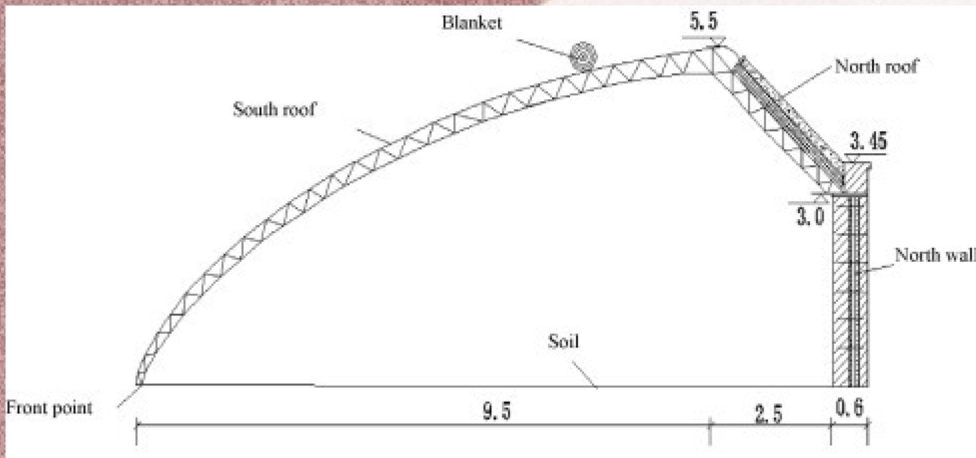
Community-supported agriculture

- Urbanites contract with a farm for a share of the produce, which is delivered
- Helps farm’s economic sustainability (cash in advance, fewer middlemen), though needs work on scale economies
- Gives urbanites a chance to advocate for agricultural sustainability in "their" farm

Urban agriculture

- Widespread in poor countries, regaining favor in rich
- Can take advantage of urban resources (graywater, stormwater, food waste, heat island) that otherwise would be costs
- Needs municipal support as legitimate land use

Growing in the winter



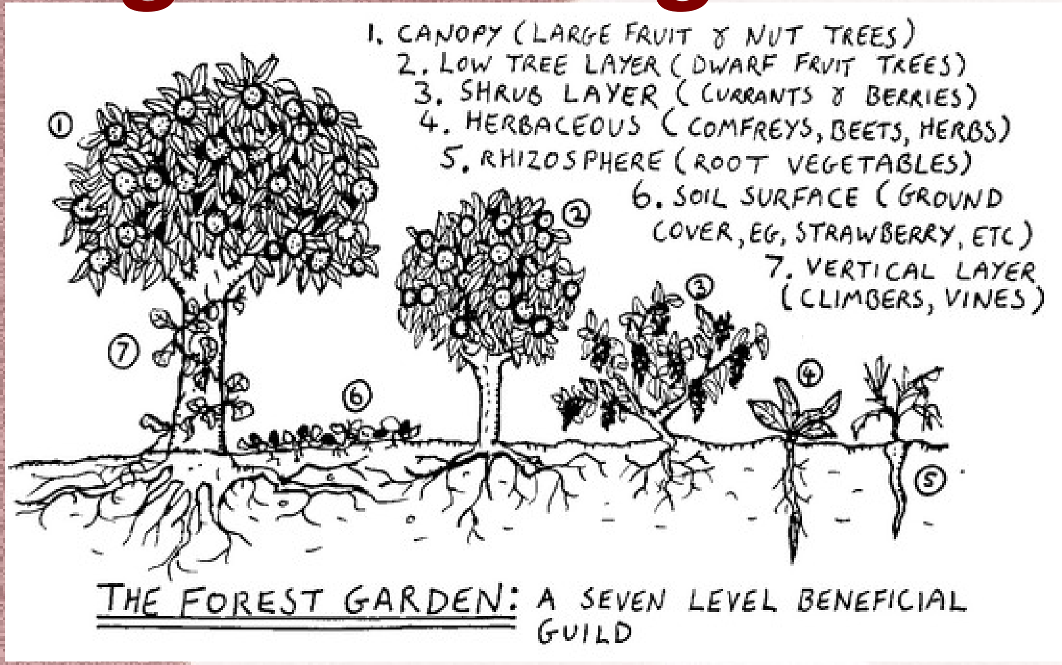
- Done (in China and Manitoba) at low capital cost against insulated south-facing walls with plastic sheets (covered with a blanket at night)
- Inside maintained at > 10 °C without heating even when outside is below -20 °C

Tong et al., Numerical modelling of temperature variations in a Chinese solar greenhouse (2009)

Vertical farming?

- Dickson Despommier (Columbia Veterinary) and students have been looking at growing food in tall buildings, enabling control of growing conditions and nutrient and water recycling
- Unclear if worthwhile, because capital-intensive – recall that ambient exergy is horizontally diffuse

Permaculture: deliberate agro-ecological design



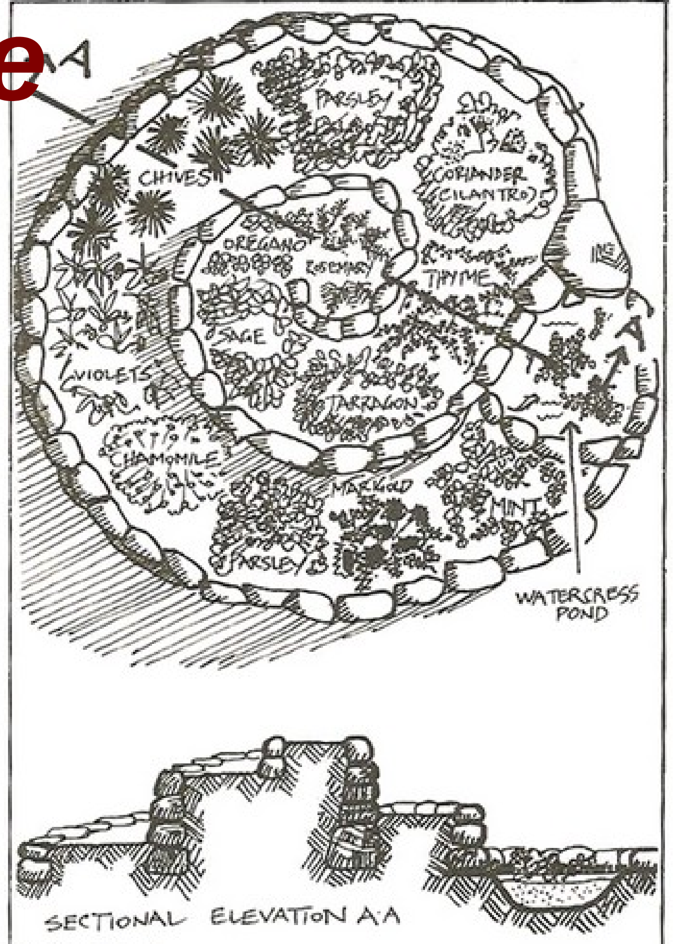


FIGURE 4. 30
HERB SPIRAL.
Pattern applied. A modest 2 m diameter by 1 m high earth spiral accommodates all necessary culinary herbs close to the kitchen door and can be watered with one 2 m sprinkler—a considerable saving in space and water as the ramp and walls exceed 9 m of plant space.

- Learns from successful traditional farming and natural ecology
- Looks for beneficial interactions between species to build low-maintenance polycultures
- Exploits or reshapes landscape features to manage water flow and crop exposure to sunlight
- Economics still problematic due to subsidies (plus free waste disposal [C-N-P]) for industrial agriculture

12 Permaculture principles (David Holmgren)

- 1. Observe and interact - By taking the time to engage with nature we can design solutions that suit our particular situation.
- 2. Catch and store energy - By developing systems that collect resources when they are abundant, we can use them in times of need.
- 3. Obtain a yield - Ensure that you are getting truly useful rewards as part of the work that you are doing.
- 4. Apply self-regulation and accept feedback - We need to discourage inappropriate activity to ensure that systems can continue to function well.

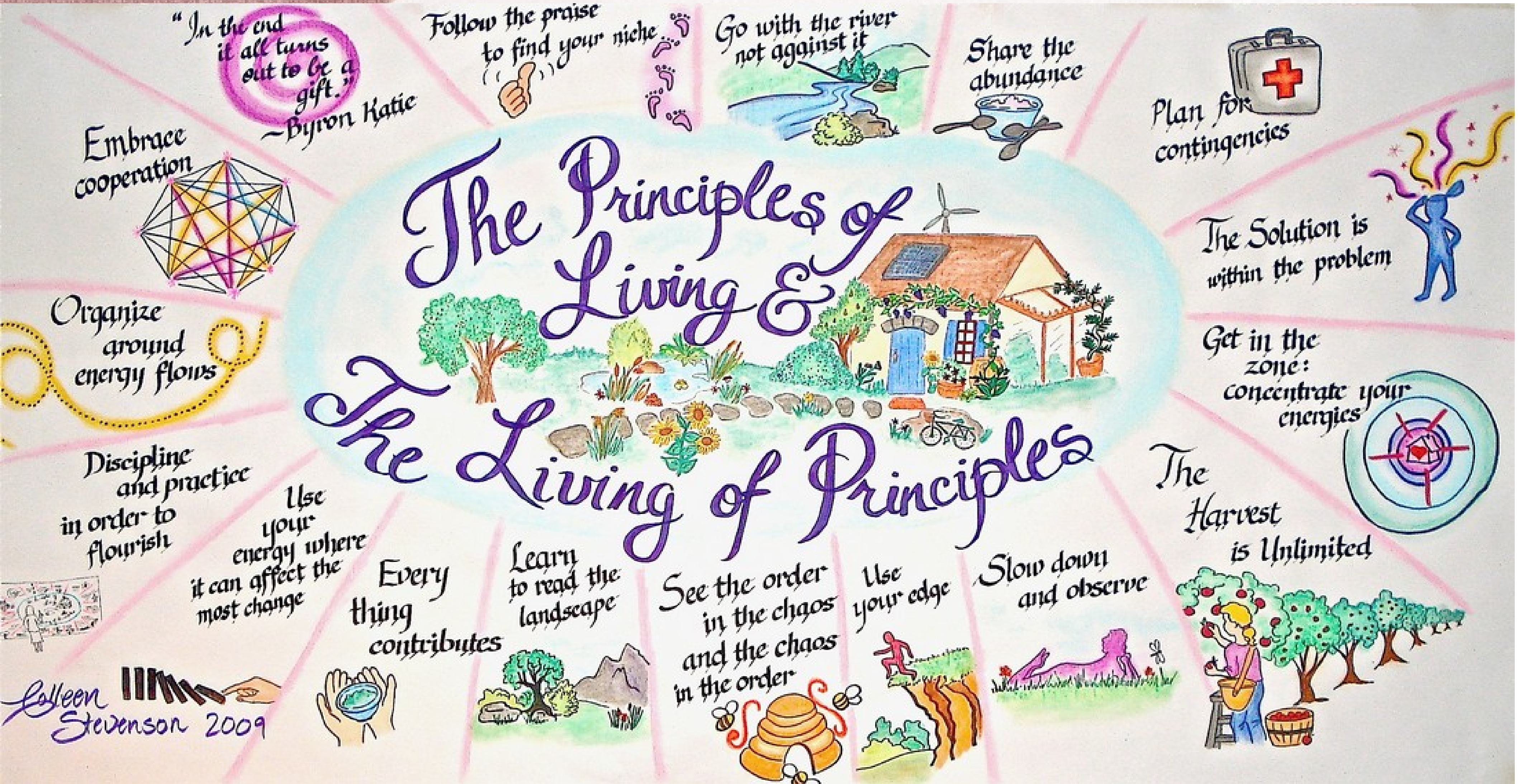
Permaculture principles

- 5. Use and value renewable resources and services - Make the best use of nature's abundance to reduce our consumptive behaviour and dependence on non-renewable resources.
- 6. Produce no waste - By valuing and making use of all the resources that are available to us, nothing goes to waste.
- 7. Design from patterns to details - By stepping back, we can observe patterns in nature and society. These can form the backbone of our designs, with the details filled in as we go.
- 8. Integrate rather than segregate - By putting the right things in the right place, relationships develop between those things and they work together to support each other.

Permaculture principles

- 9. Use small and slow solutions - Small and slow systems are easier to maintain than big ones, making better use of local resources and producing more sustainable outcomes.
- 10. Use and value diversity - Diversity reduces vulnerability to a variety of threats and takes advantage of the unique nature of the environment in which it resides.
- 11. Use edges and value the marginal - The interface between things is where the most interesting events take place. These are often the most valuable, diverse and productive elements in the system.
- 12. Creatively use and respond to change - We can have a positive impact on inevitable change by carefully observing, and then intervening at the right time.

Permaculture maxims



One assessment of the potential

Geoff Lawton, an Australian permaculture teacher living in Jordan, says that “all the world’s problems can be solved in a garden” ... While this statement suffers from some hyperbole, it also contains an important truth: insofar as the current model of industrial agriculture is a major contributor to many of the world’s most pressing ecological problems—including water and energy usage, climate change, and pollution by toxic chemicals, as well as social problems such as poverty and hunger—these problems can only be effectively addressed by fundamentally changing our agricultural systems.

Ultimately, to bring about a successful transition to agroecology ... would require both changes in government policies and changes in basic assumptions about food production, and indeed in the way we relate to food itself.

Mark D. Hathaway, "Agroecology and permaculture: addressing key ecological problems by rethinking and redesigning agricultural systems", Journal of Environmental Studies and Sciences 6:239–250 (2016)