Global and local effects of agriculture on groundwater resources

– processes and examples

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Outline

- Why agriculture is the greatest thing on earth (and the worst)
- Deforestation now and the forgotten deforestation of old
- The lighter side of deforestation
- Why the green revolution is somewhat blue
- Nuclear-powered farming in India?
- Our craving for a very abundant but elusive element
- Why Europe imports air from South America

  (and why European groundwaters suffer from that)
- Why Germany needs another country of its own size

Impact of agriculture

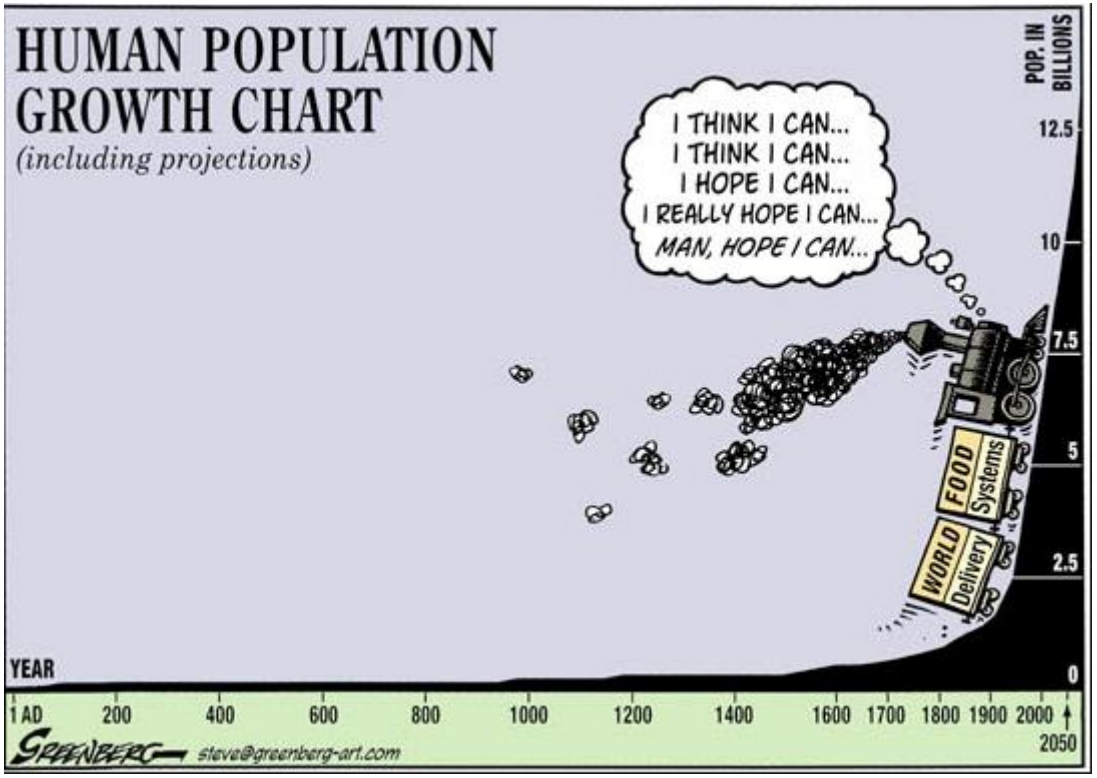
☺

- Employs a lot of people (1.3 billion, 30-40 % of global workforce)
- Feeds us, well almost all of us (99.99 %)

☹

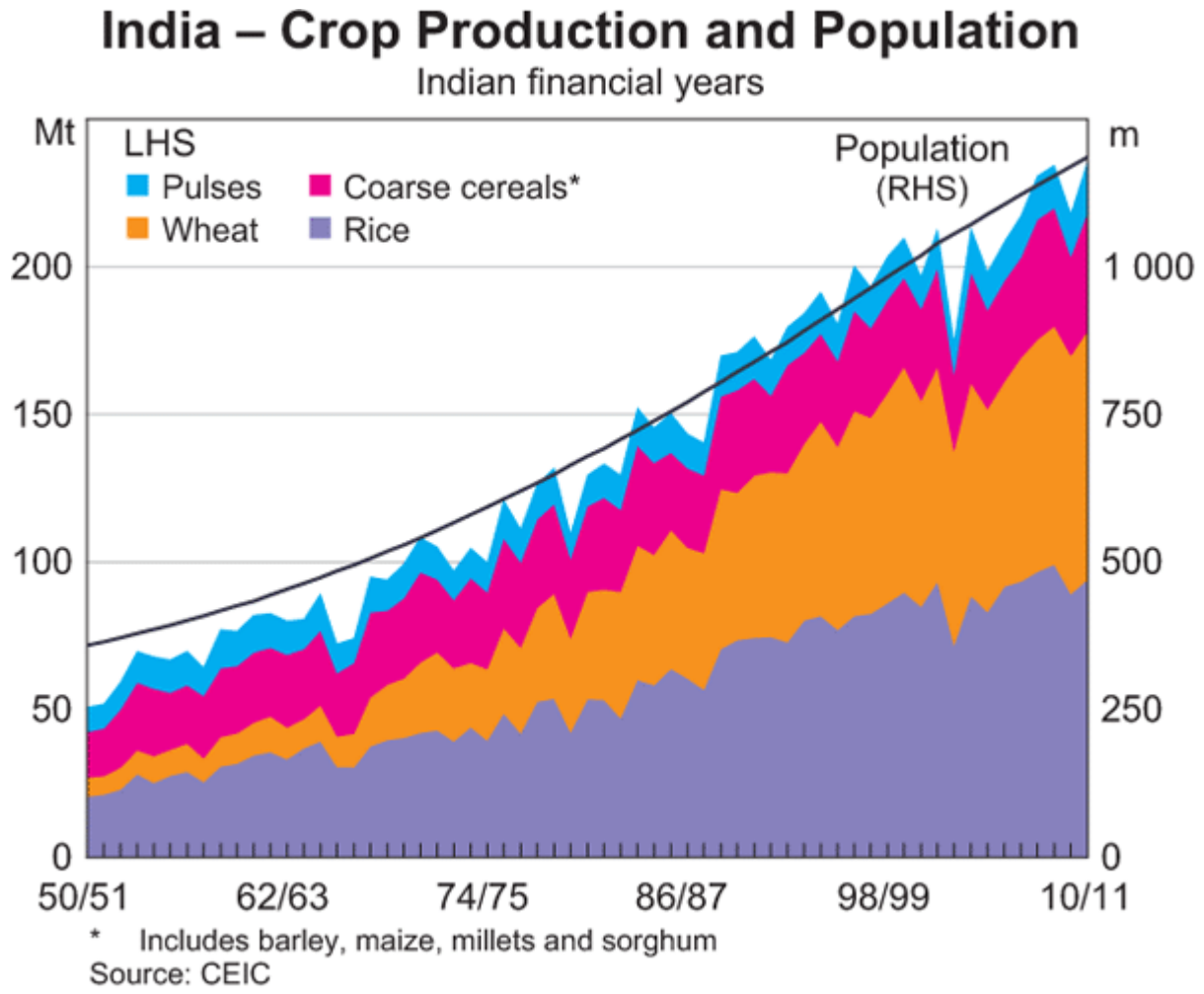
- Spatial demand: deforestation, habitat destruction, biodiversity loss (but also: cultivated landscapes)
- Water demand (irrigation), water footprint of products
- Energy demand (pumping, fertilizer & pesticide production …)
- Nitrogen, phosphate, carbon, potassium cycles:
    - Fertilizers and manure…
- Pesticides
- Greenhouse gases
- Soil degradation and erosion
- …

Population growth and food demand – how do we cope?

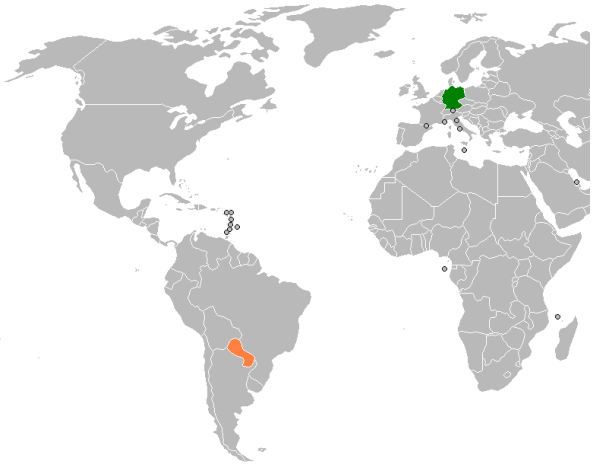


- Increase arable land
- Increase efficiency by:
  - mechanization
  - better techniques (e.g. no-till)
  - adequate nutrient supply
  - control of pests
  - better water supply (irrigation)
  - international trade

Population growth and food production: India



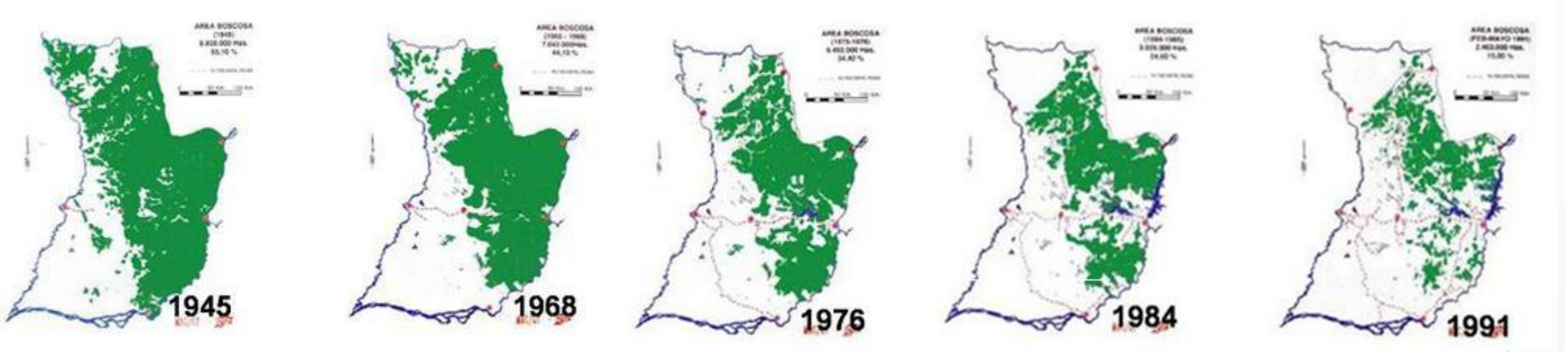
A tale of two countries

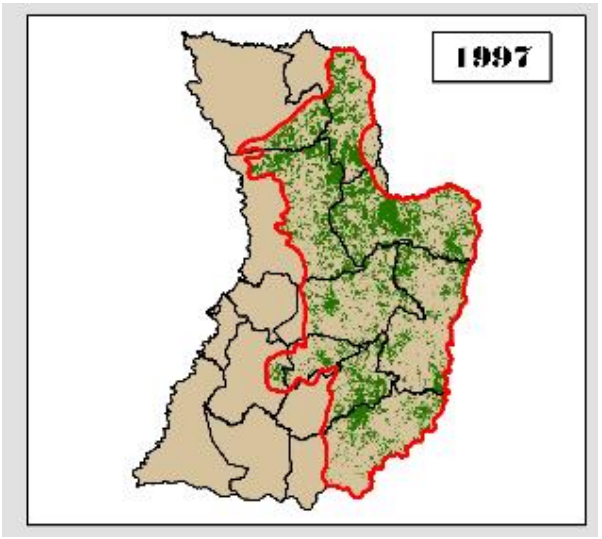


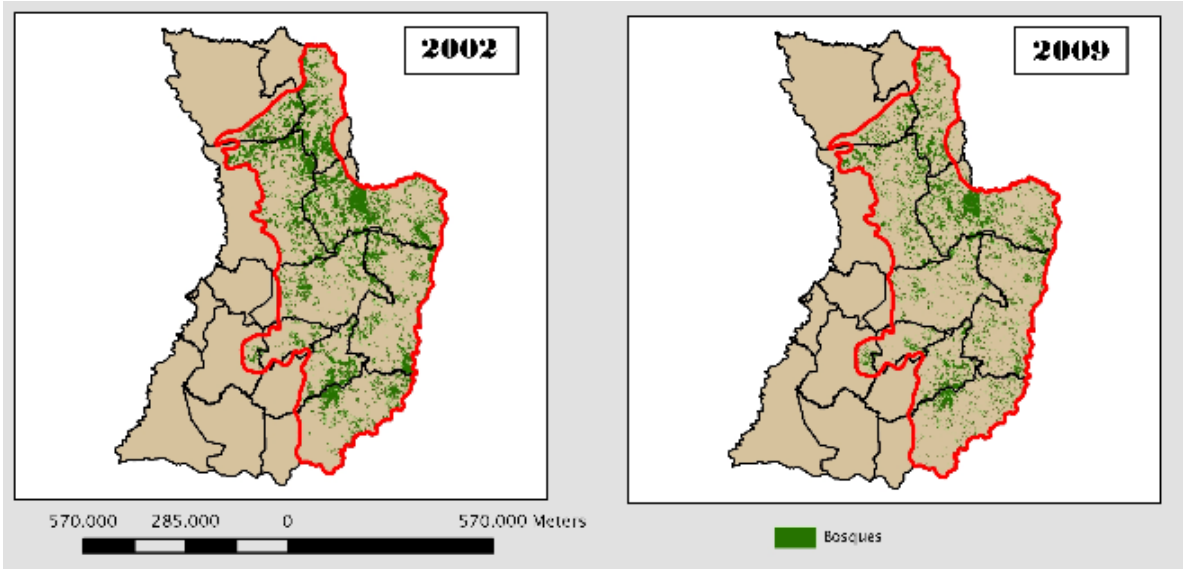
		Paraguay	Germany
Area	[km²]	406,752	357,021
Population		6.8 million	82.2 million
Pop. density	[/km²]	17.2	227
Per capita GDP	[US-$]	9,779	42,200
HDI		0.693	0.926
Arable land	[%]	11	34
Pasture	[%]	43	13
Forest area	[%]	44	30
Agricult. GDP	[%]	27	2
Agricultural workforce	[% of pop.]	45	2

From various sources

Creating space: deforestation of Eastern Paraguay

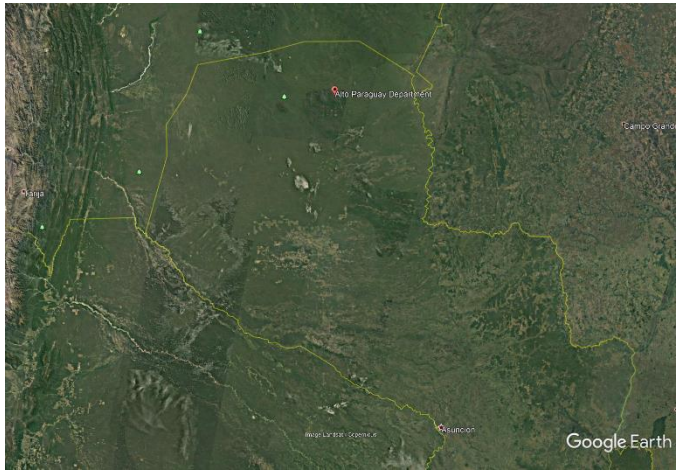




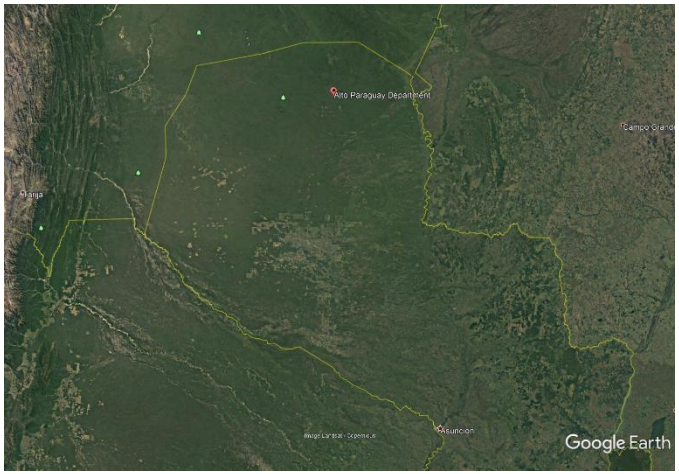


Deforestation in fast forward mode: the Chaco

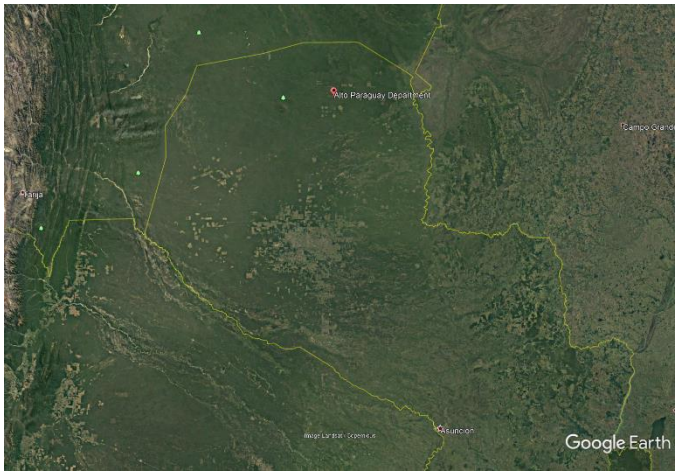
1984



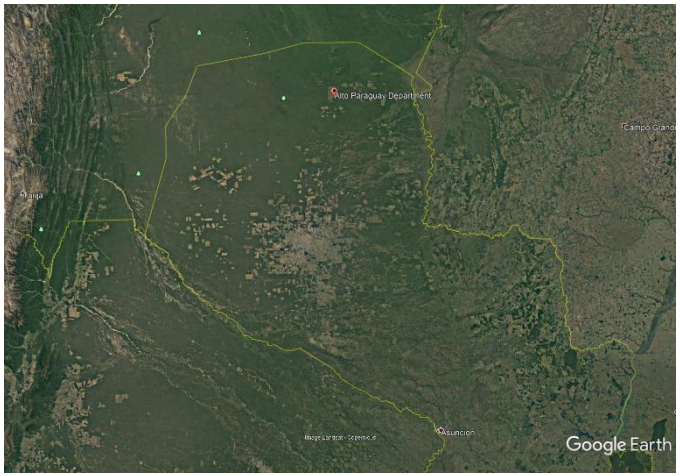
1992



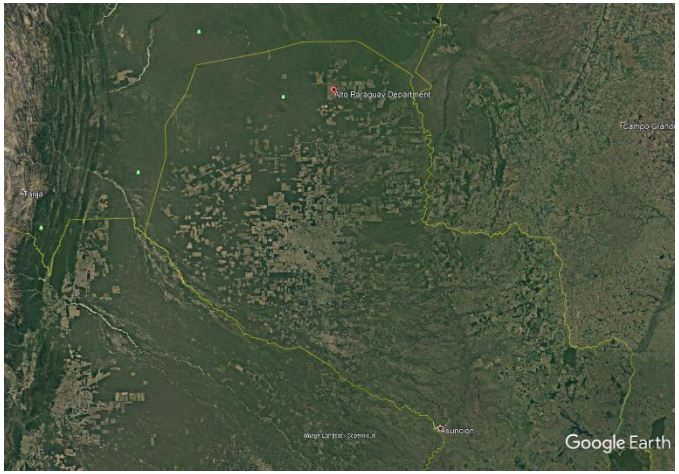
1998



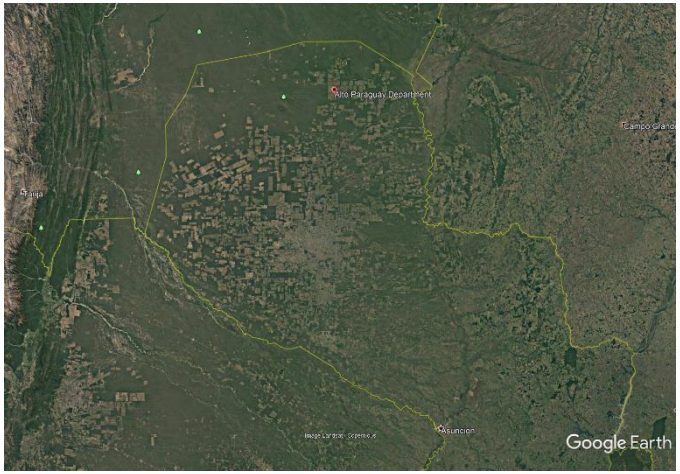
2004



2011

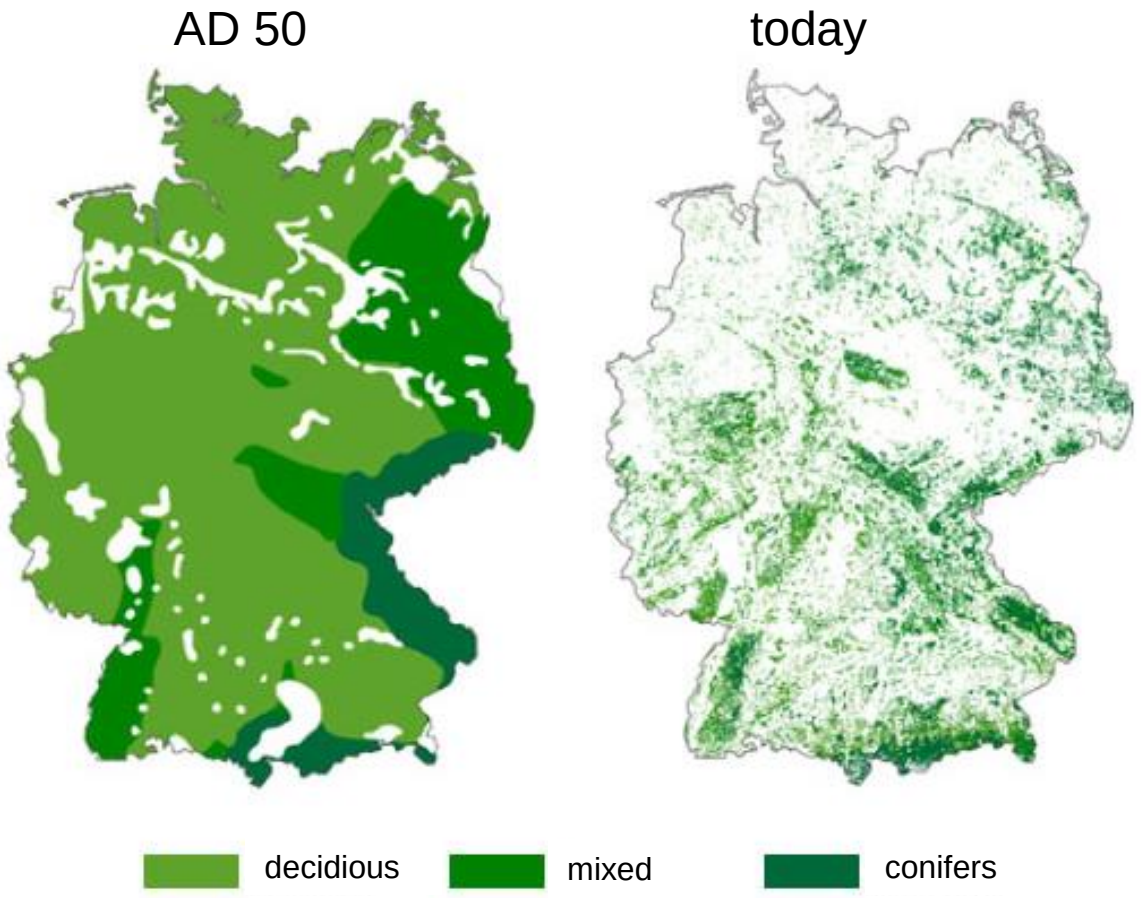


2016



Rate ≈ 200,000 ha/a (2008)

Deforestation of Germany



Quelle: Prof. Dr. Hansjörg Küster, Diercke Atlas, Global Land Cover Facility © ZEIT ONLINE

Deforestation complete by the 14th century

The lighter side of deforestation

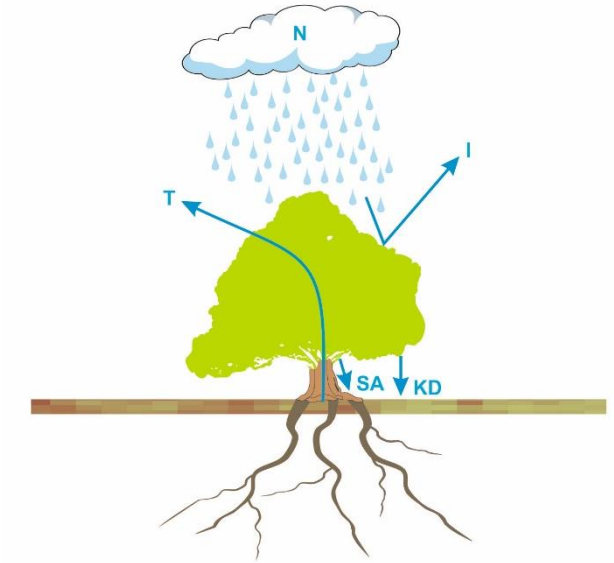
Transpiration & interception

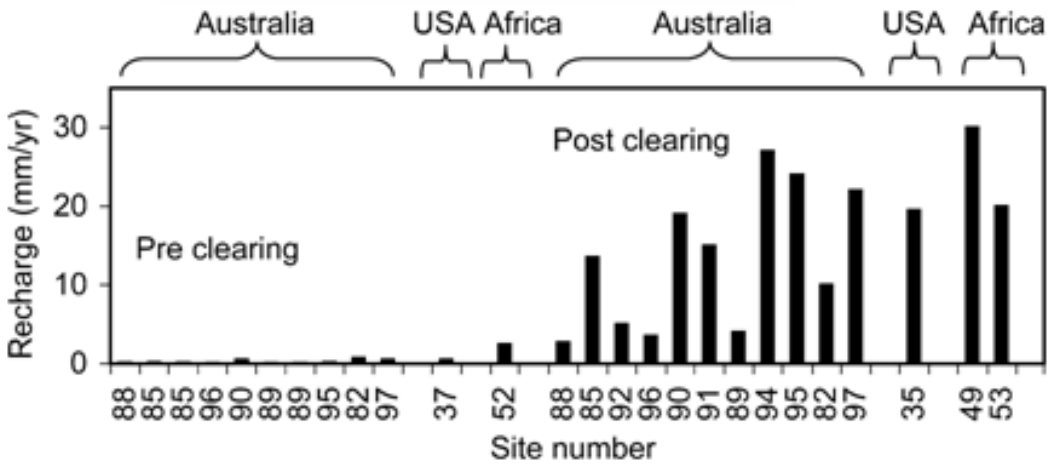
Water release during vegetation phase

- birch 60-70 l/d, hot days: up to 400 l/d
- 100 a old beech 400 l/d
- large oak tree 150,000 l/a
- sunflower1 l/d
- wheat 10,000-15,000 l/a*ha

Interception:

- conifers (needle):
  30-40% of rainfall throughout year
- deciduous trees (leaves):
  10-20% during winter, 20-30%
  (or more) during summer
- agricultural crops:
  10-25 % during vegetation phase

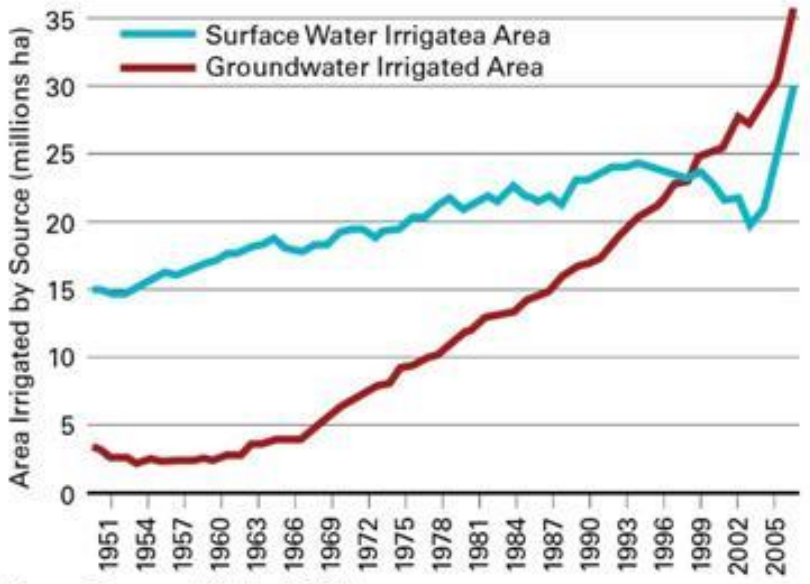




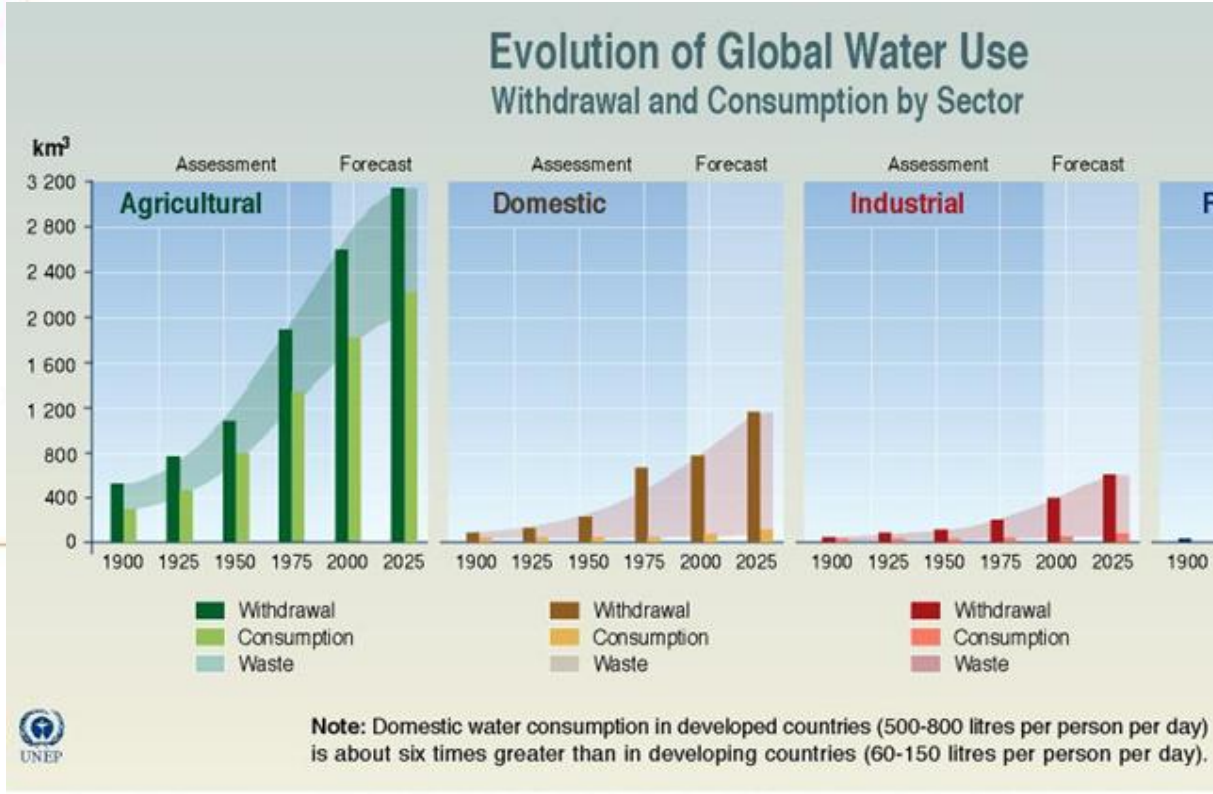
Source: Scanlon 2006

How blue is the green revolution?

Surface Water and Groundwater Irrigation Use Growth in India, 1951–2007



Source: Faures and Mukherji (2011)



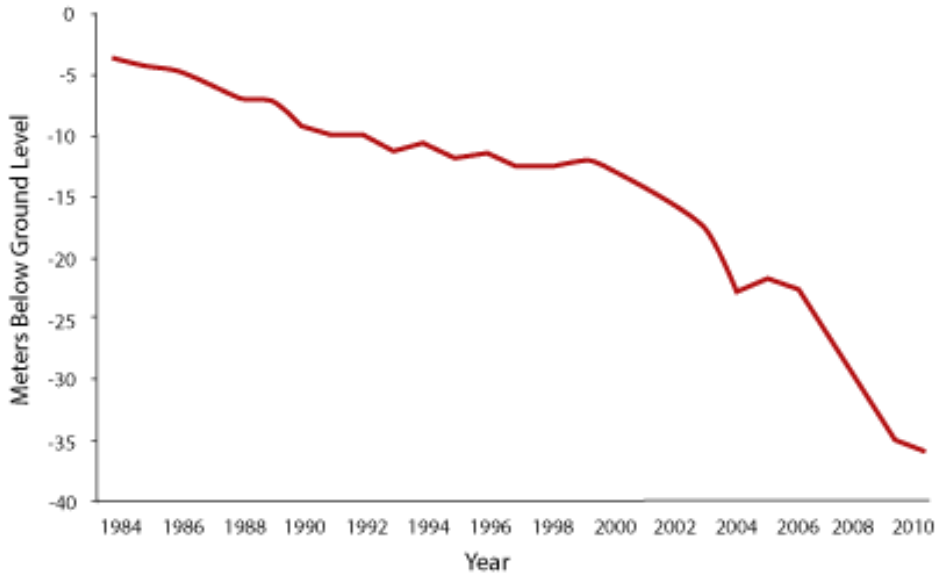
Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Org

Global Harvest INITIATIVE

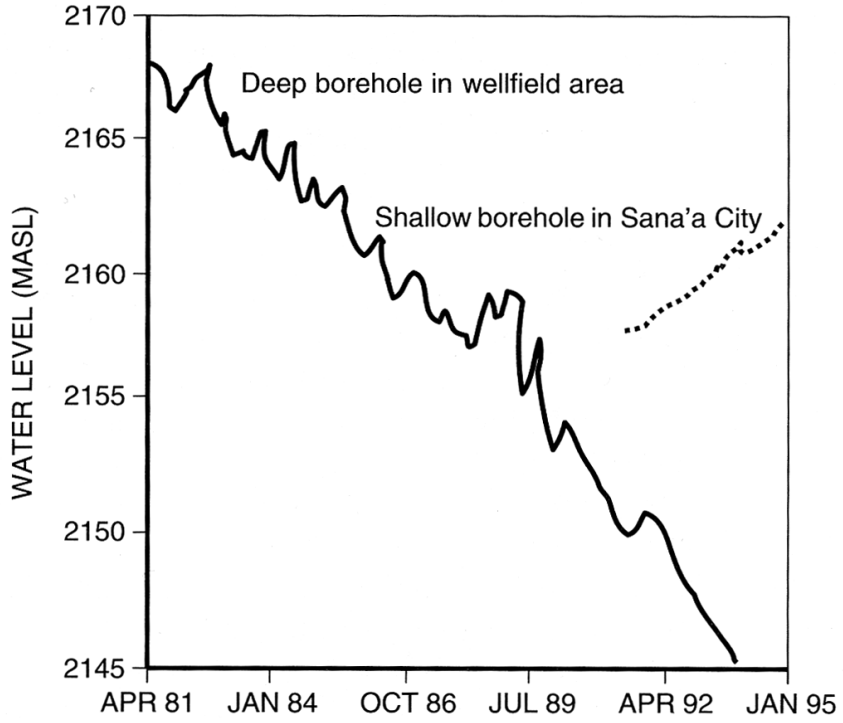
2014 GAP Report®

Unsustainable use: examples

Figure 1. Groundwater levels in Kaladera area



Source: Central Groundwater Board, Rajasthan Groundwater department. (Data provided by India Resource Center.)



Sana´a, Jemen:	10^6 m³/a
gw recharge	23 to 38
gw extraction	120 to 173
balance	- 82 to -150 (negative!)

Quelle: Foster et al. 2003 IGRAC

Unsustainable use: examples

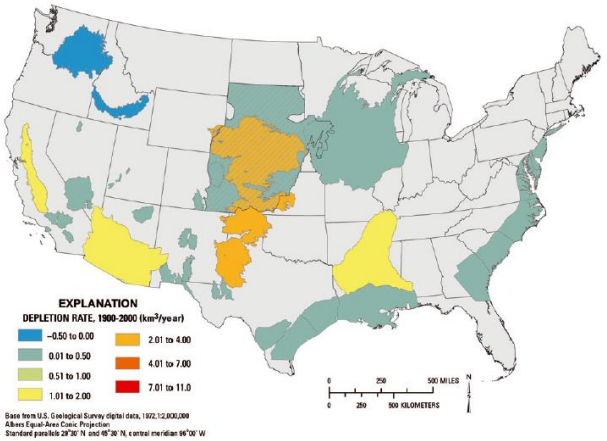
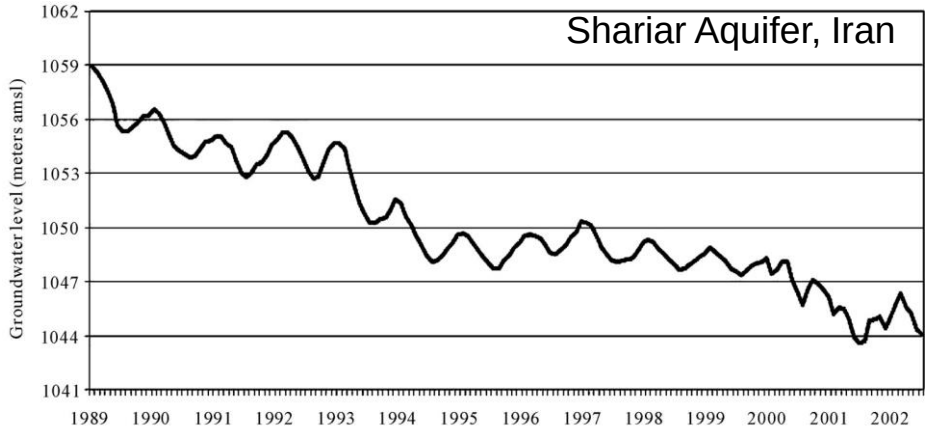
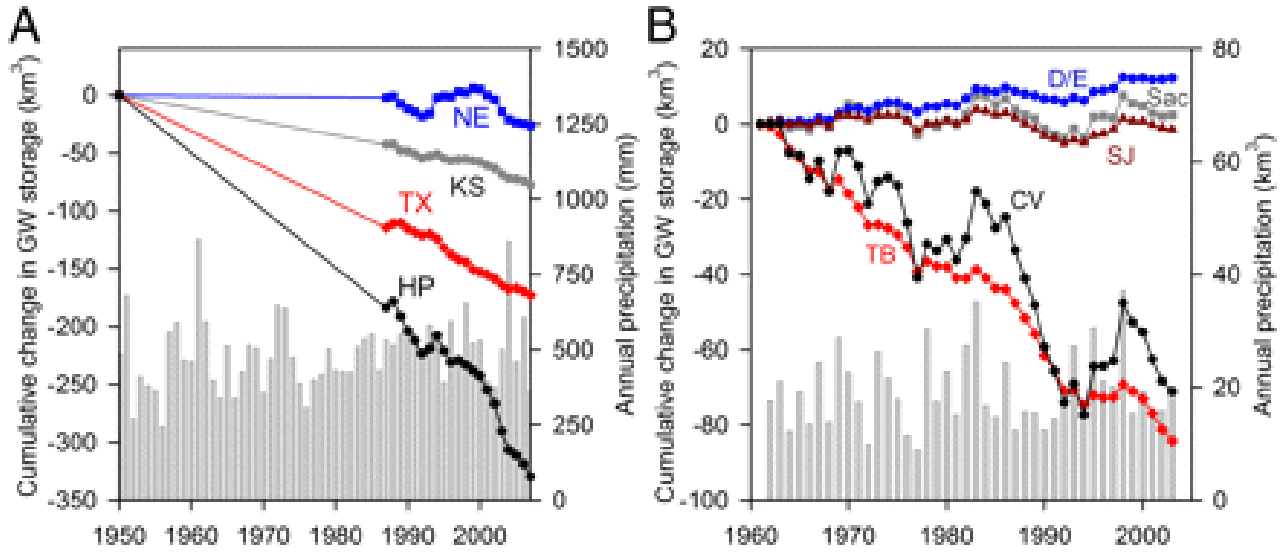


Figure 1. Average groundwater depletion rate during 1900–2000 in 40 assessed aquifer systems or subareas in the conterminous 48 states.





HP = High Plains Aquifer
CV = Central Valley Aquifer
D/E, Delta, Eastside;
Sac, Sacramento;
SJ, San Joaquin; TB, Tulare Basin

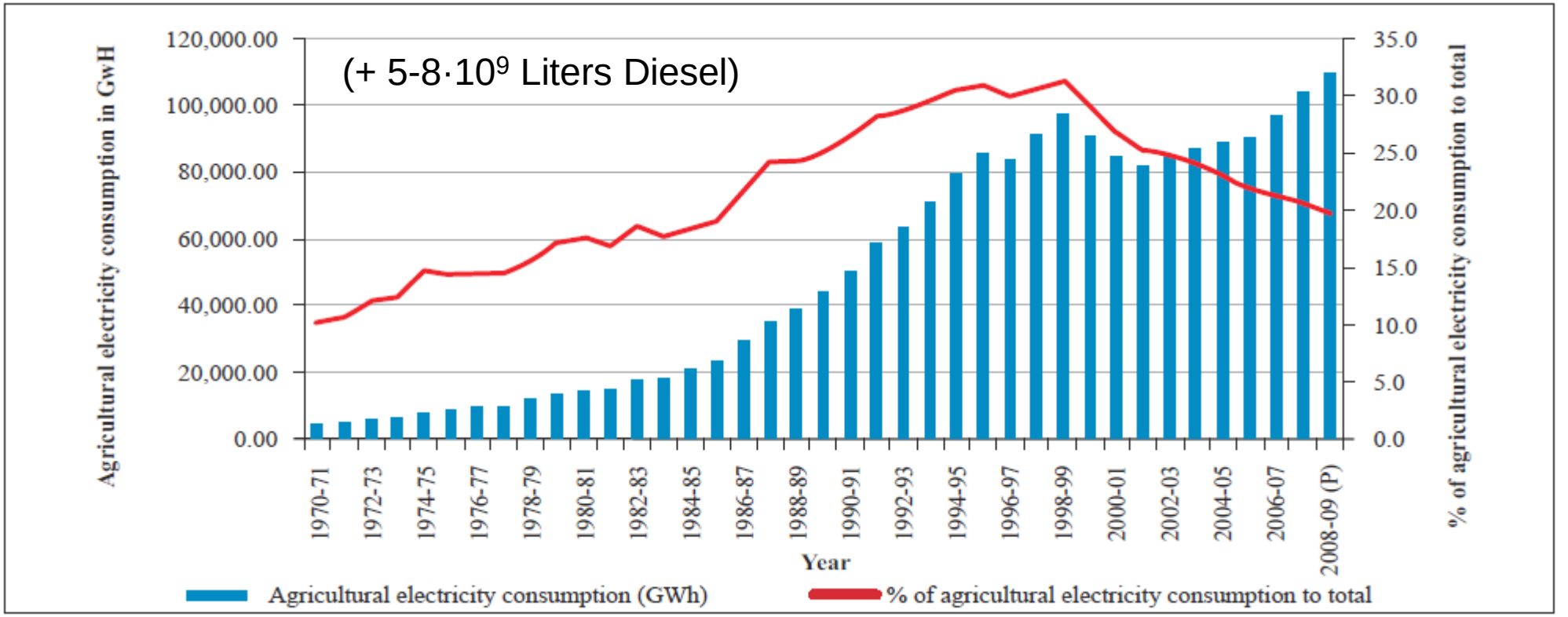
Sources: USGS, Khodapanah et al. 2011; Scanlon 2012

Water supply and energy consumption

Country	Primary energy for water supply	Electrical energy for water supply	Groundwater Abstraction	Agricultural abstraction	Wells
	[%]	[%]	[km³]	[%]	
Germany	0.5		8.5	1.2	40,000
Netherlands			1.7	20	11,000
France	1.6	3.4	6.3	18	>30,000
USA	1.6	4.3	110	80 (42)	16,000,000
Canada			2		1,700,000
Saudi-Arabia	3.7		21	83-88	110,000
Iran		(15, agricult.)	29-74	92	365,000
China	1.7	5.5	110-150	60	
India	8.9	20-30	150		20,000,000

From various sources, see Houben 2015, Aquastat

Groundwater irrigation and electricity: India



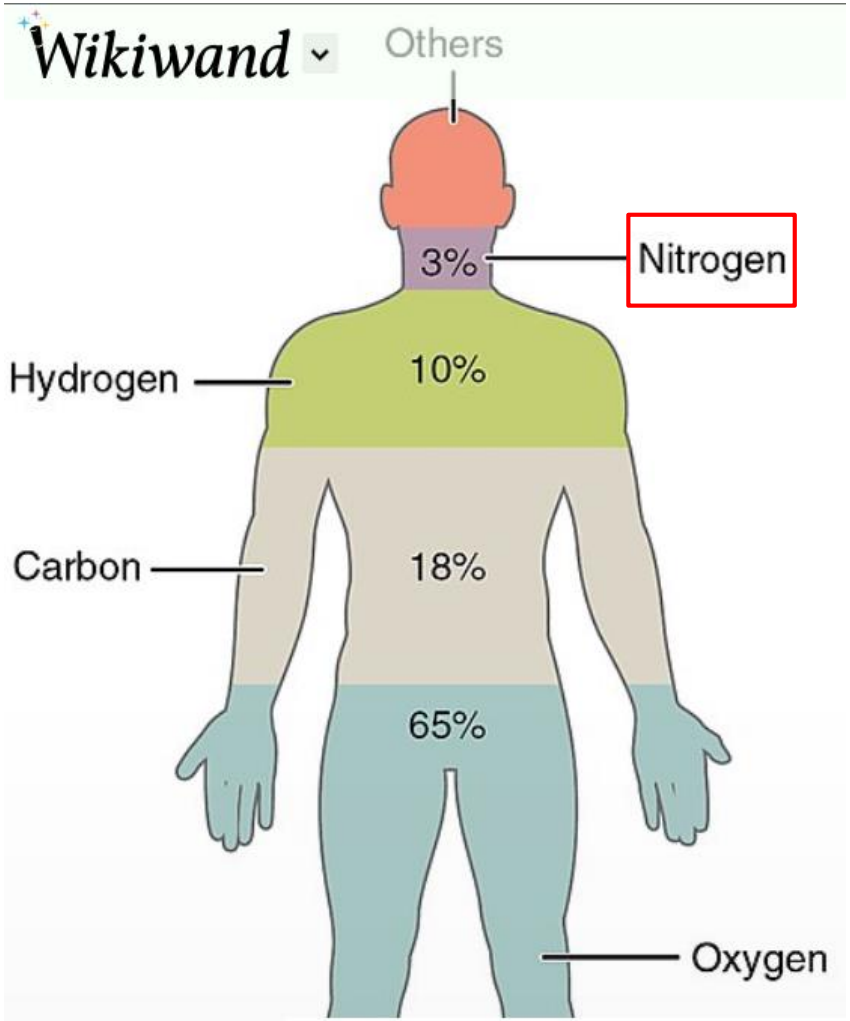
Source: Data from Central Electricity Authority, published in GoI 2007 and 2010

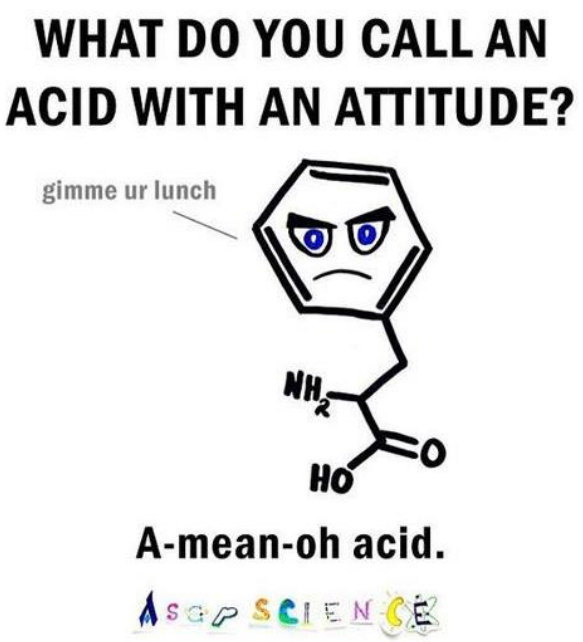
(Shah et al. 2004)

Estimated number of wells: 20 million!!!

Agriculture needs 100,000 GWh, nuclear power provides 30,300 GWh

Chasing an essential nutrient: nitrogen



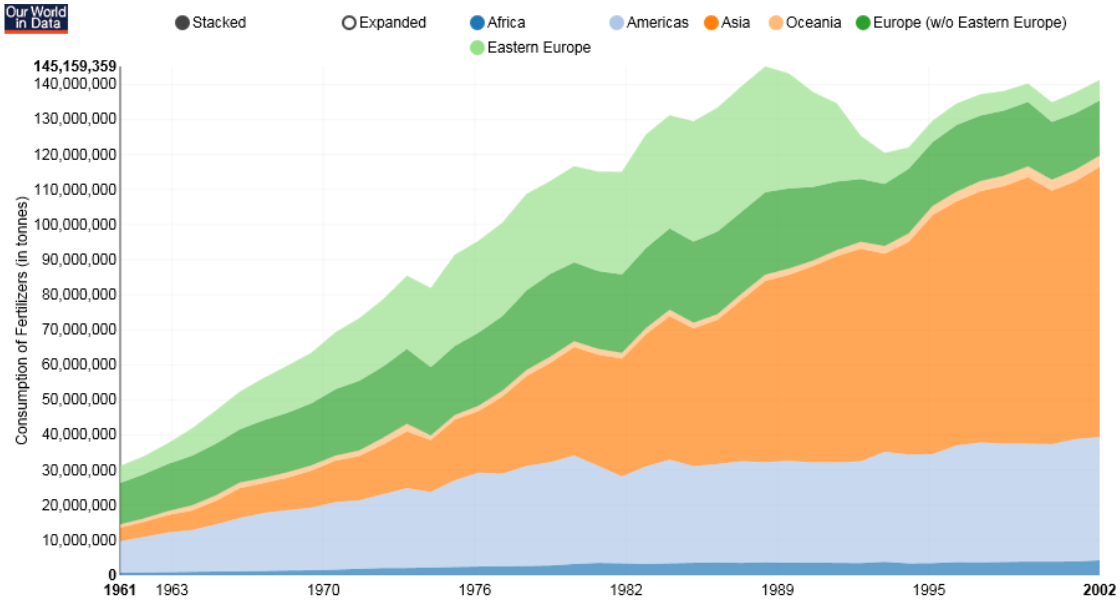


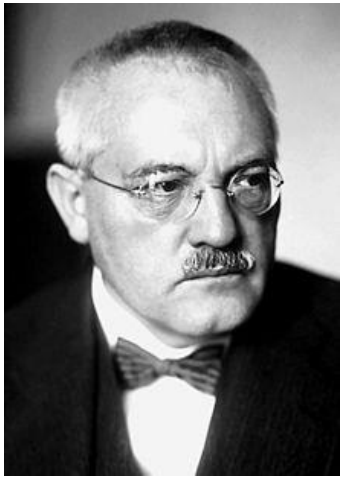
Nitrogen is essential!
78% of air is N_2 but not accesible

Sources:
- animal protein
- plant protein
- use plant protein to feed animals

Source: ASAP Science, wikiwand

Making bread from air: fertilizers



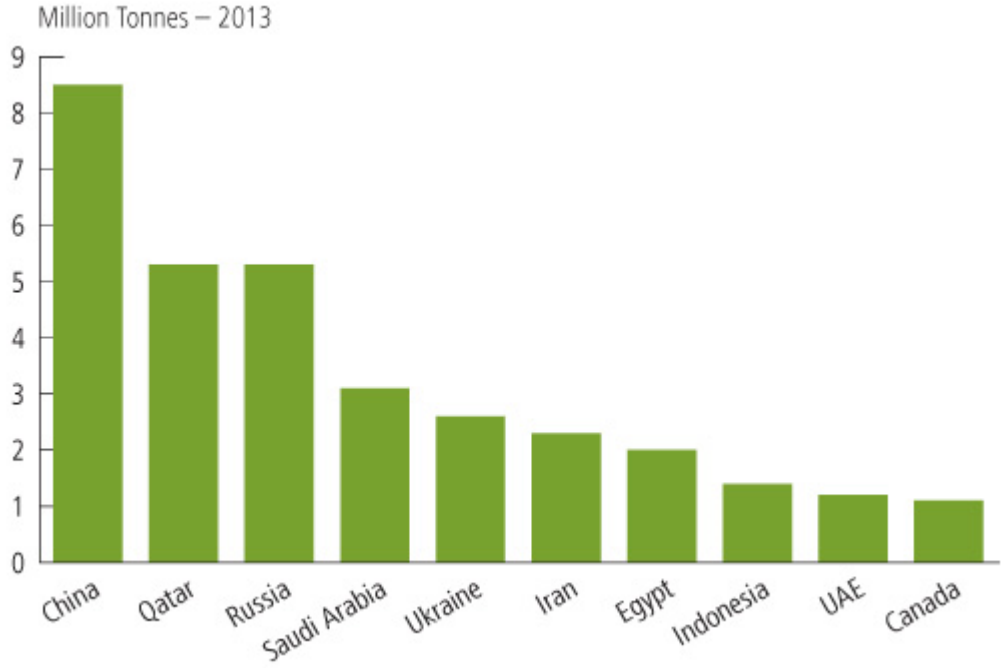


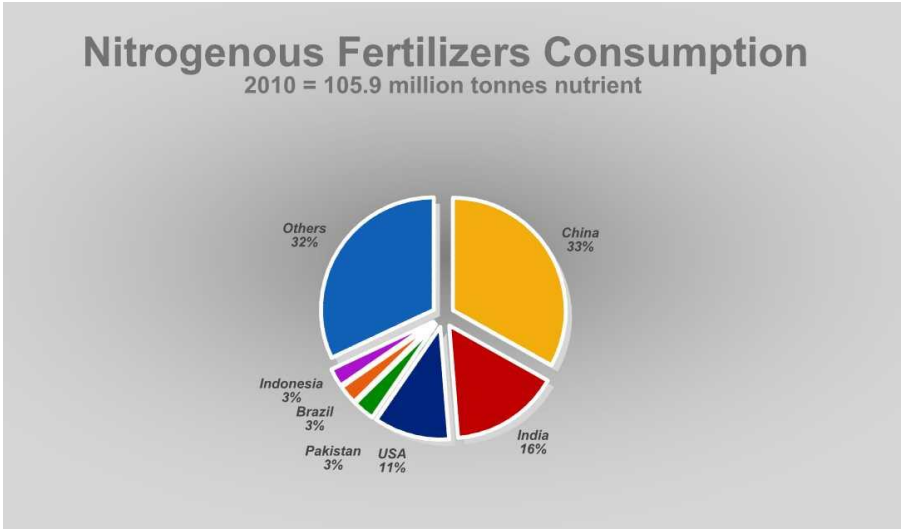
Haber-Bosch synthesis
(artificial nitrogen fixation)

Fritz Haber, nobel prize 1918
Carl Bosch, nobel prize 1931

Source: Max Roser via Our World in data, photos: wikipedia

Global nitrogen fertilizer market





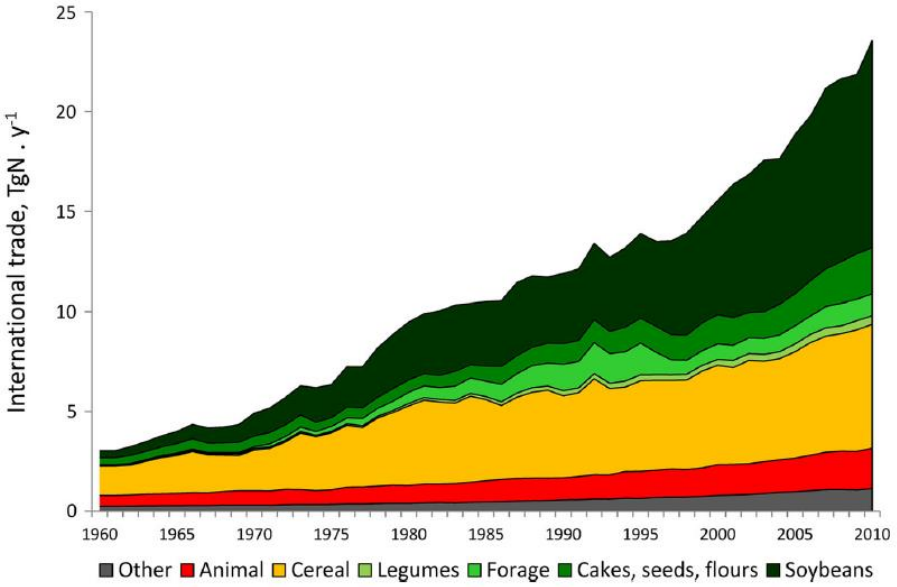
Production (2010): ≈ 100 Mio. t of nutrient
Haber-Bosch synthesis requires a lot of energy
3-5 % of world natural gas production
1-2 % of world energy supply

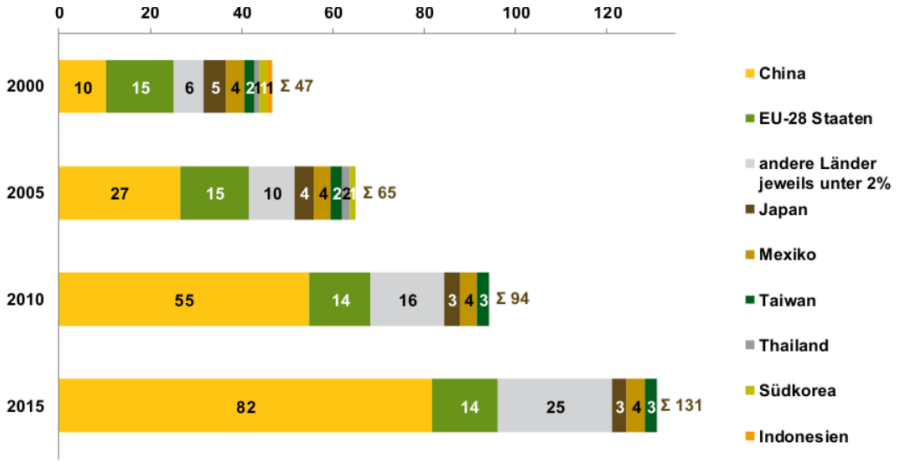
Source: Potash Corp., NPK world

Let plants (and their microbe friends) do the job: Soy beans as N fixers

Soy beans:

- grows almost anywhere
- can fix air nitrogen (with the help of bacteria)
- no nitrogen fertilizer needed
- bean has 36.5 % protein (raw)
- produces also valuable oil
- apt for human consumption (tofu …)
- apt as animal fodder → meat production
- genetically modified, round-up ready

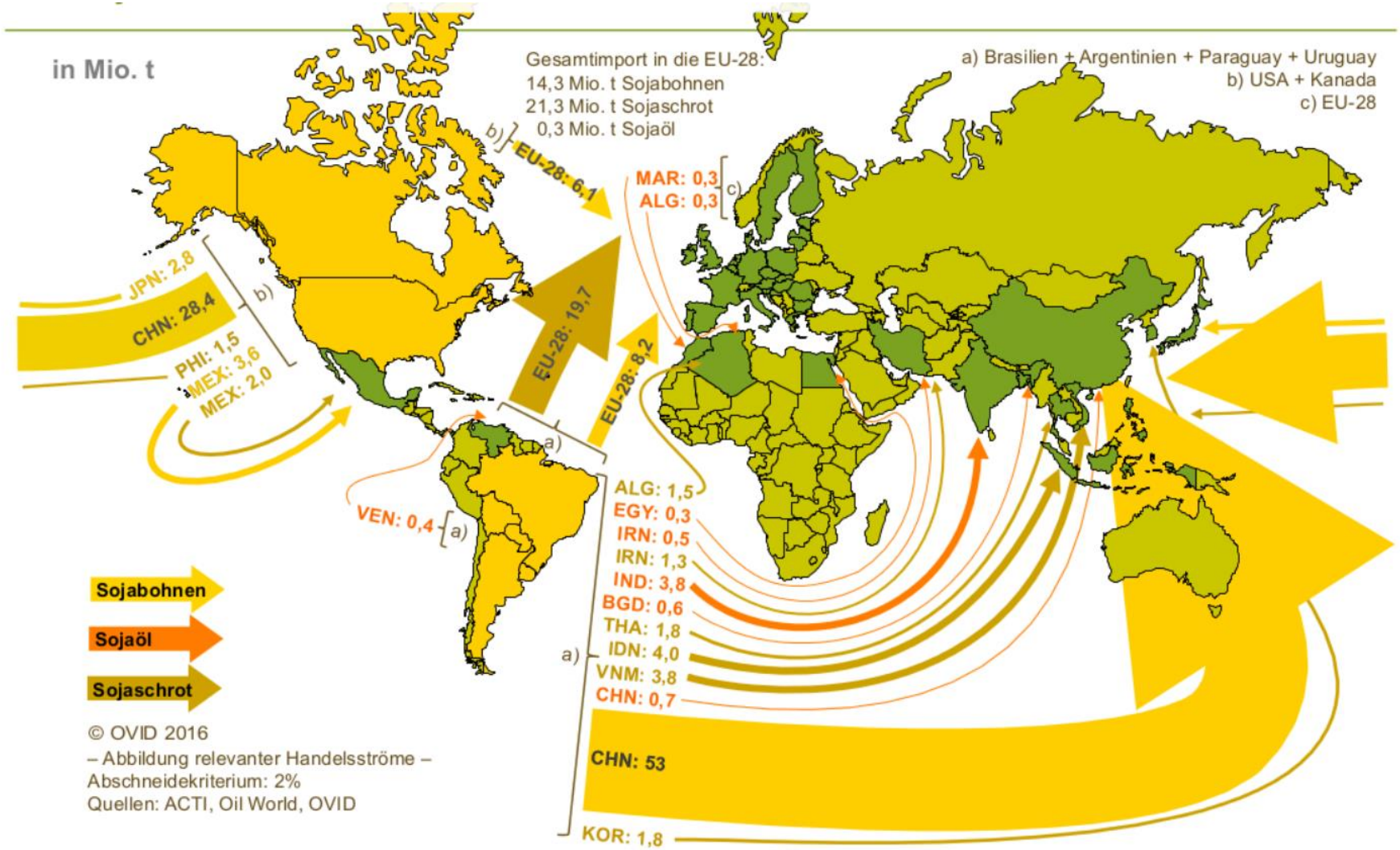




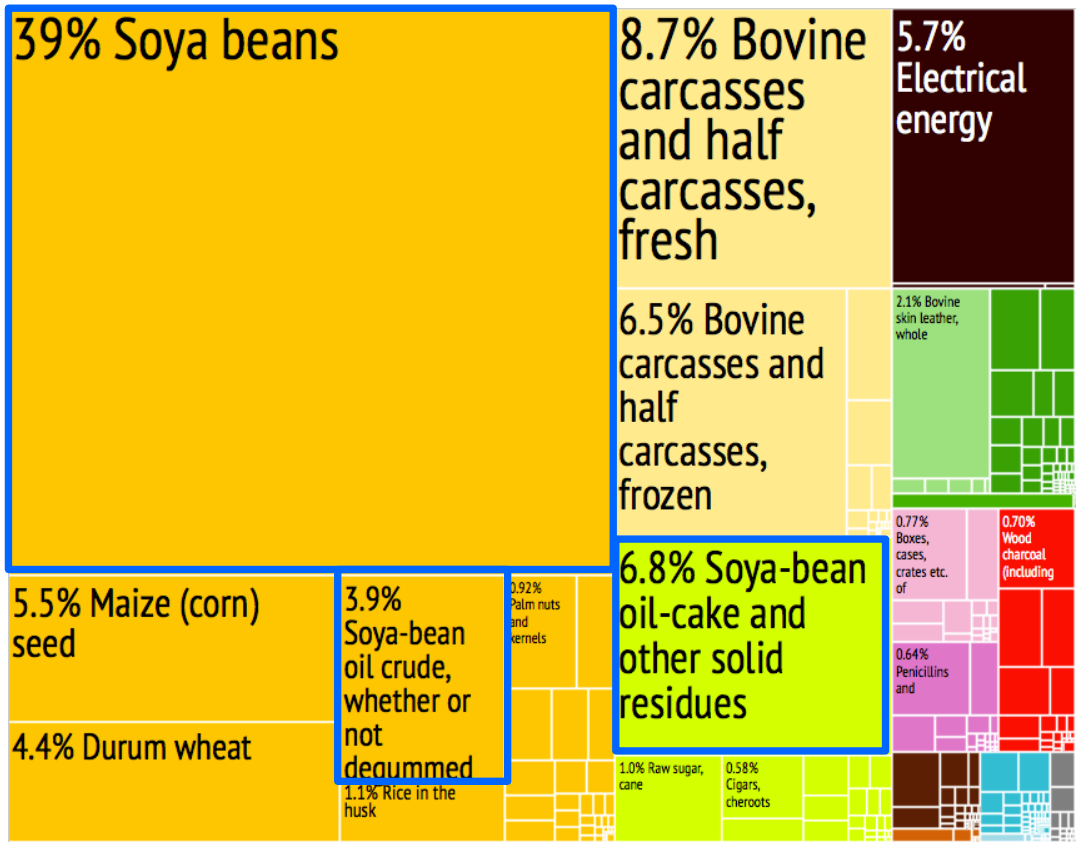
Quellen: Oil World, OVID

∑ = Summe

Global soy trade: importing air



Export products of Paraguay



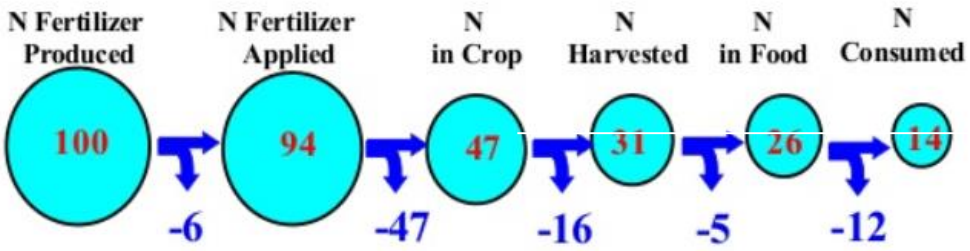
Soy beans

PY	8-10 Mt/a production (world 324 Mt/a) 3,300,000 hectares > 95% no-till agriculture 49.7 % of exports: soy products
DE import	3.7 Mt/a beans (0.3 Mt/a from PY), 2.9 Mt/a shred (0.0 Mt/a from PY) 0.085 Mt/a soy oil

Sources: wikipedia, OVID, Oil World, USDA

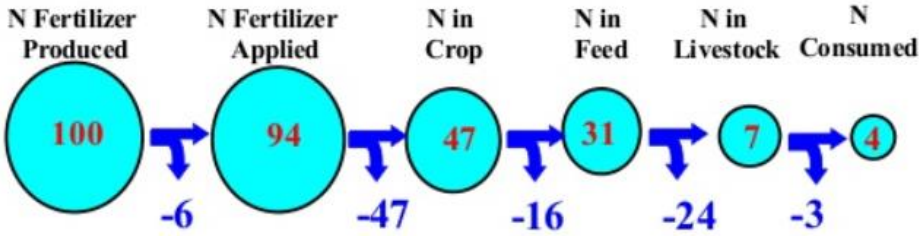
Nitrogen uptake efficiency: plants vs.animals

The Fate of Haber-Bosch Nitrogen



14% of the N produced in the Haber-Bosch process enters the human mouth……if you are a vegetarian.

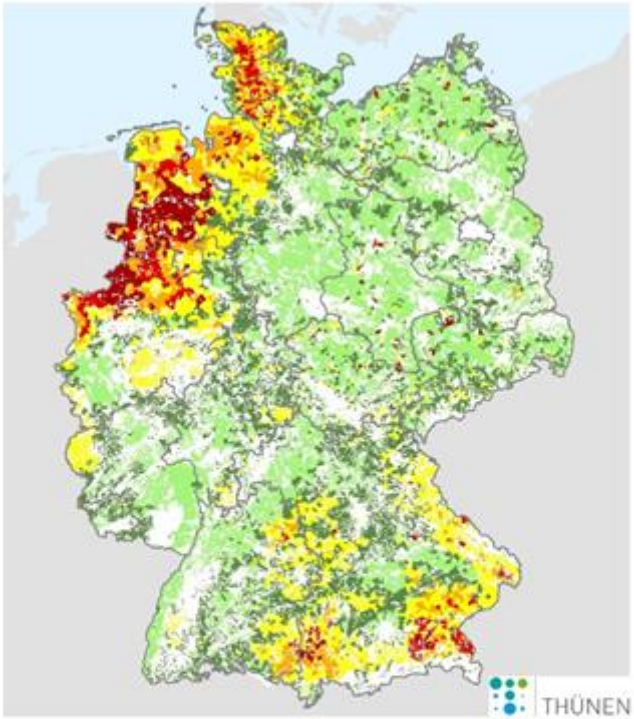
The Fate of Haber-Bosch Nitrogen



4% of the N produced in the Haber-Bosch process and used for animal production enters the human mouth.

Source: Davidson 2014

Cheap meat and excess nitrogen



Großvieheinheiten (GVE) 2010 auf LAU2 Ebene je ha LF

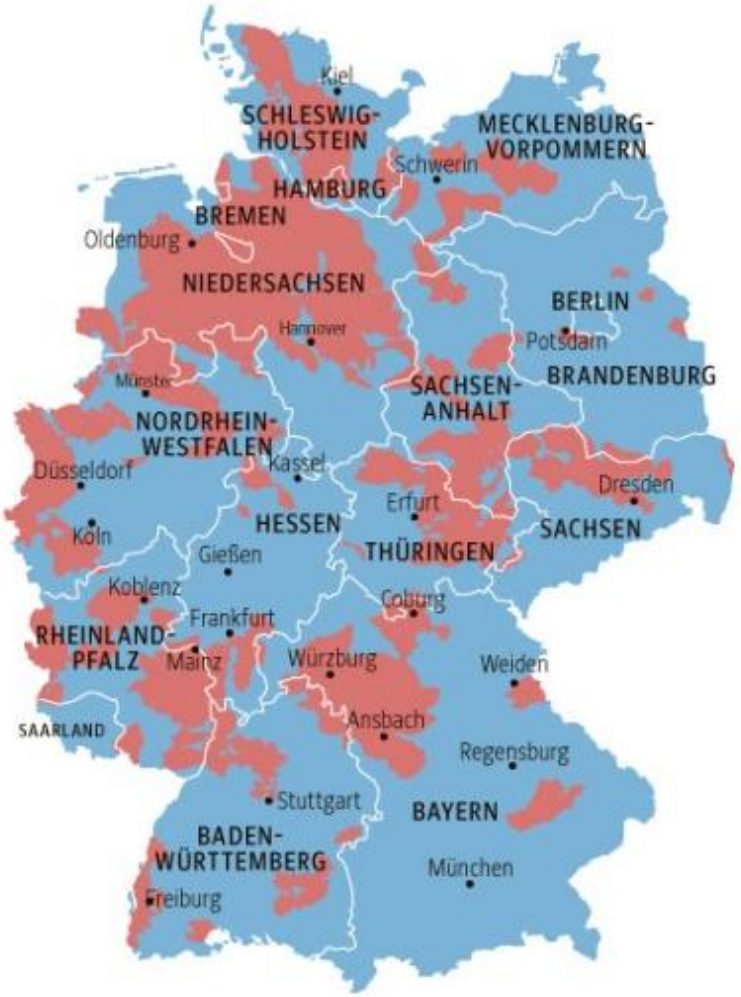
≤ 0,5 | > 0,5 bis 1,0 | > 1,0 bis 1,5 | > 1,5 bis 1,75 | > 1,75 bis 2,0 | > 2,0

Unit: large animals per ha

Sources: Thünen-Institute, BfG

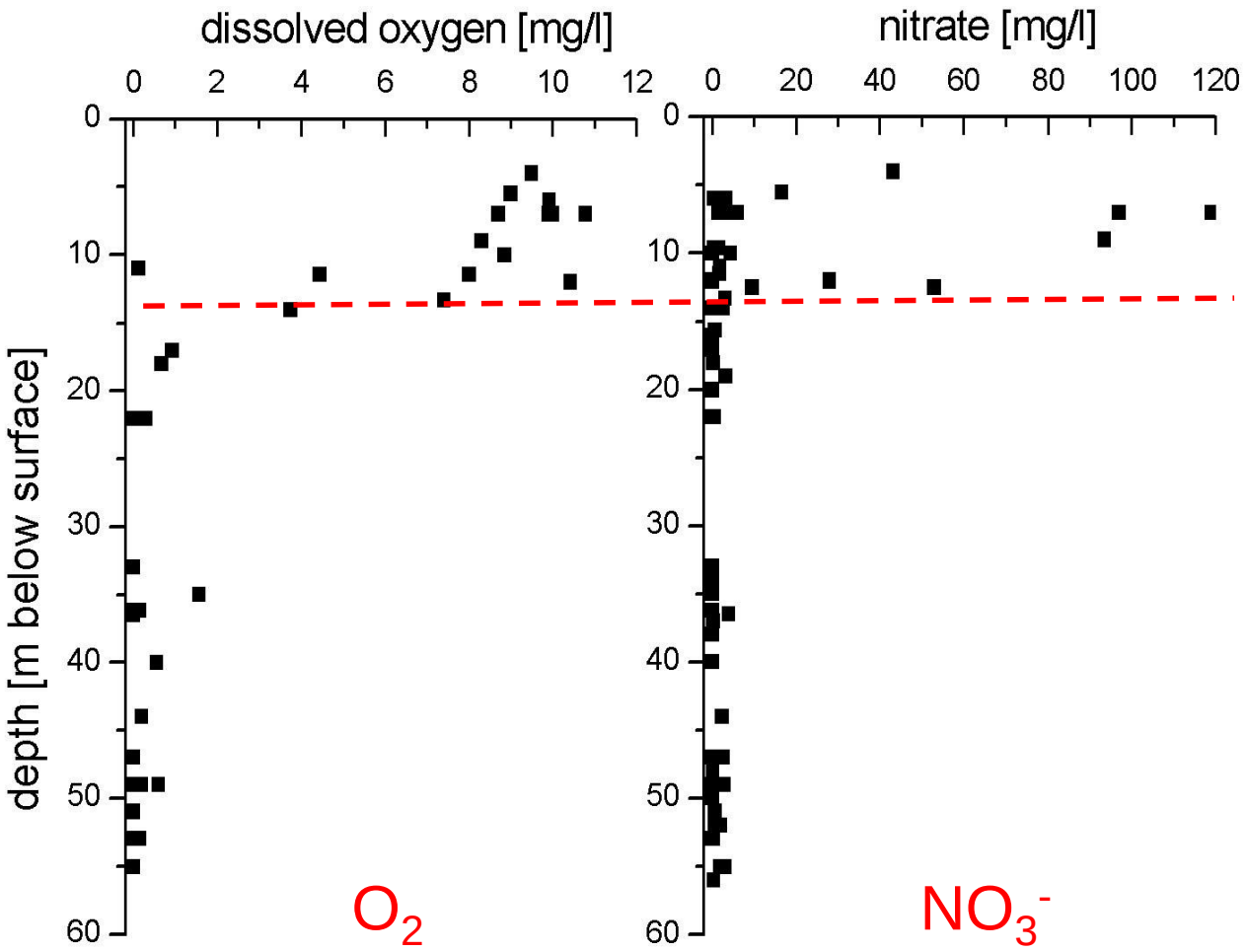
Groundwater quality (nitrate)

Good quality
Bad quality

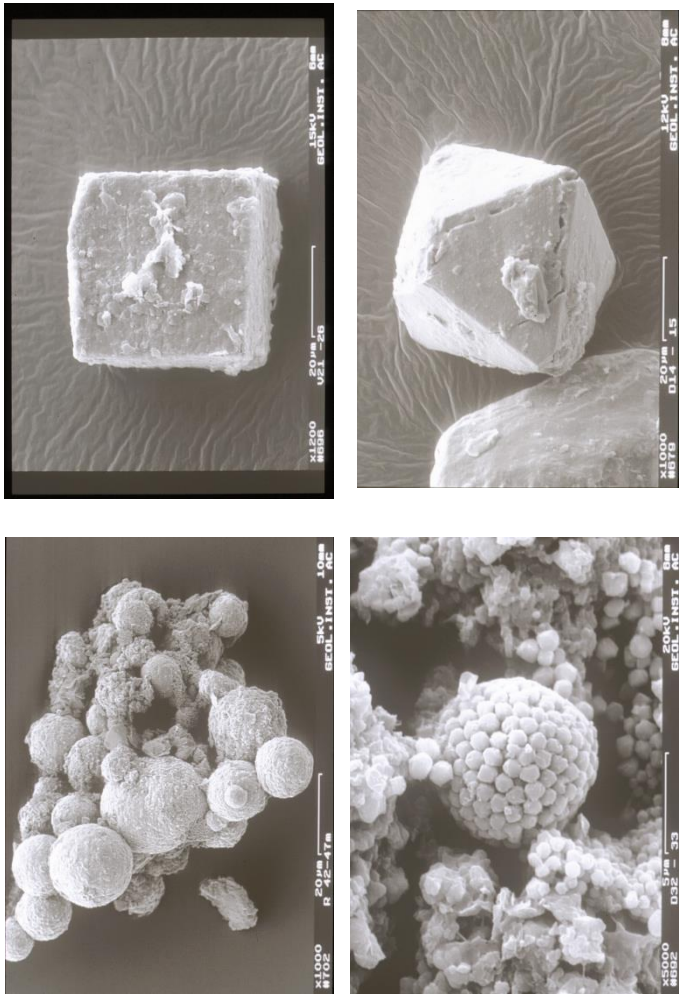


SZ-Grafik; Quelle: WasserBLICK/BfG 2010

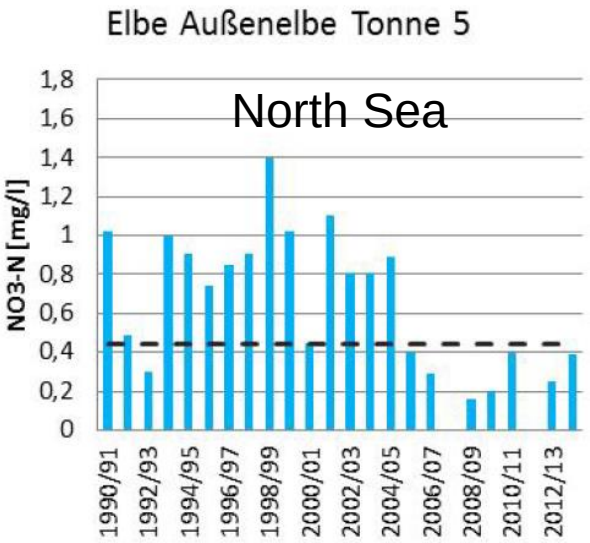
Denitrification: nature´s little helpers

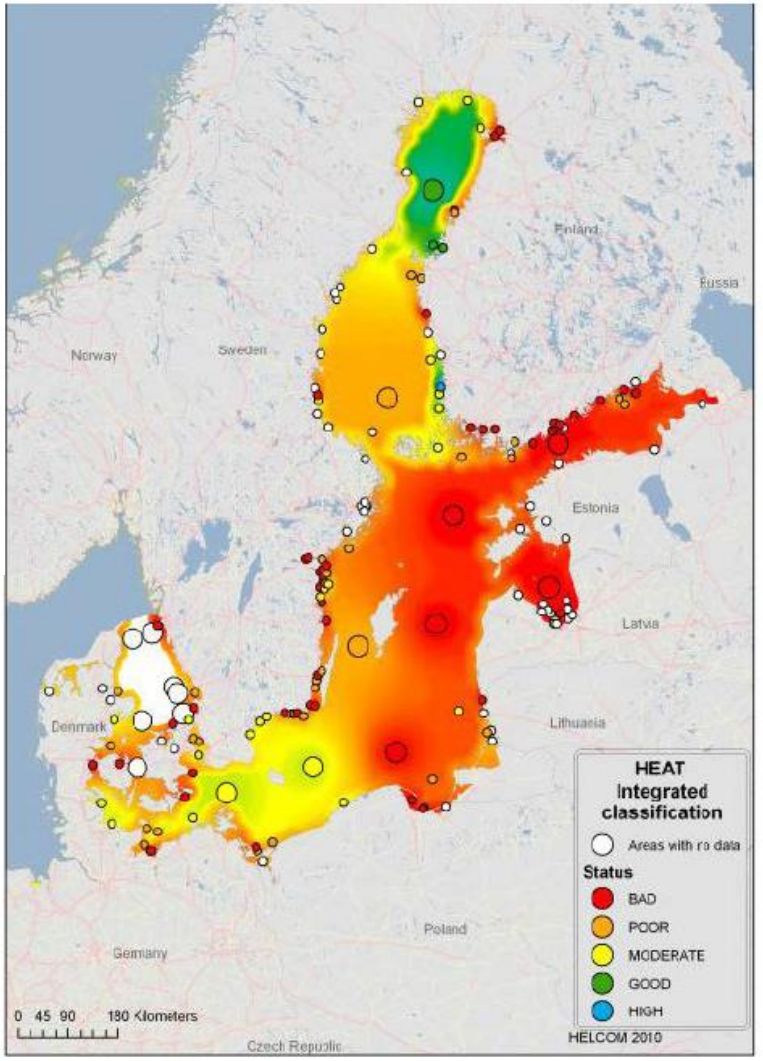


after data by Houben (2000)



Where do the nutrients end up?





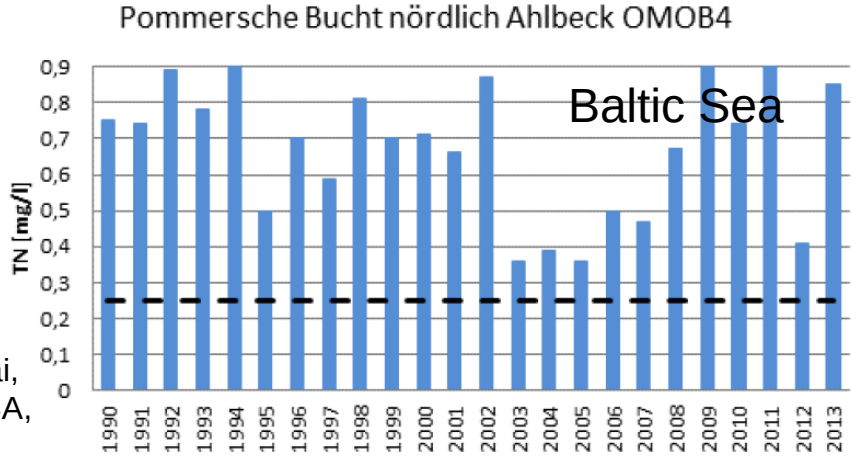
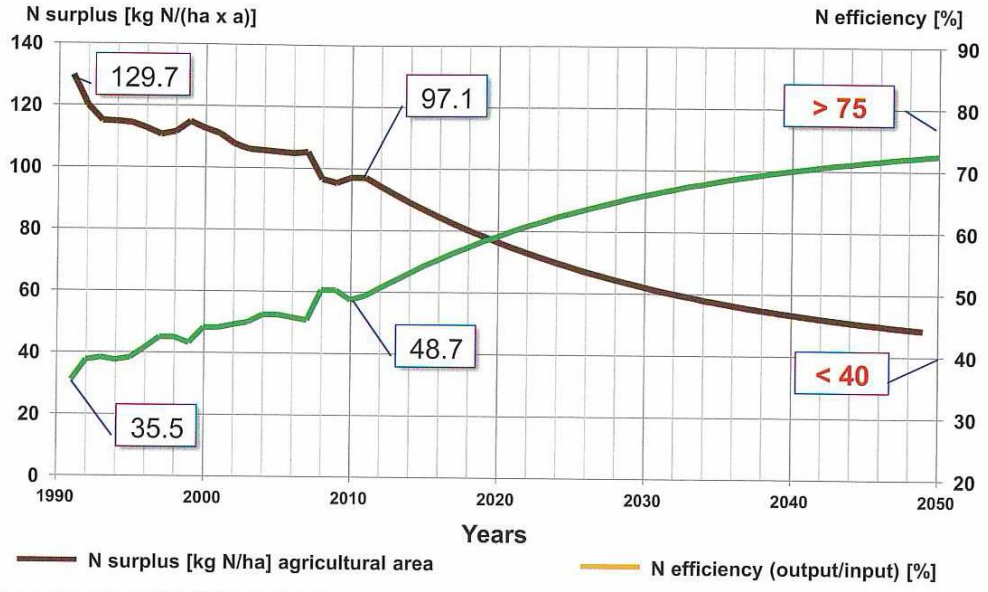


Photo: Lago Ypacarai, Houben. Graphs: UBA, HELCOM

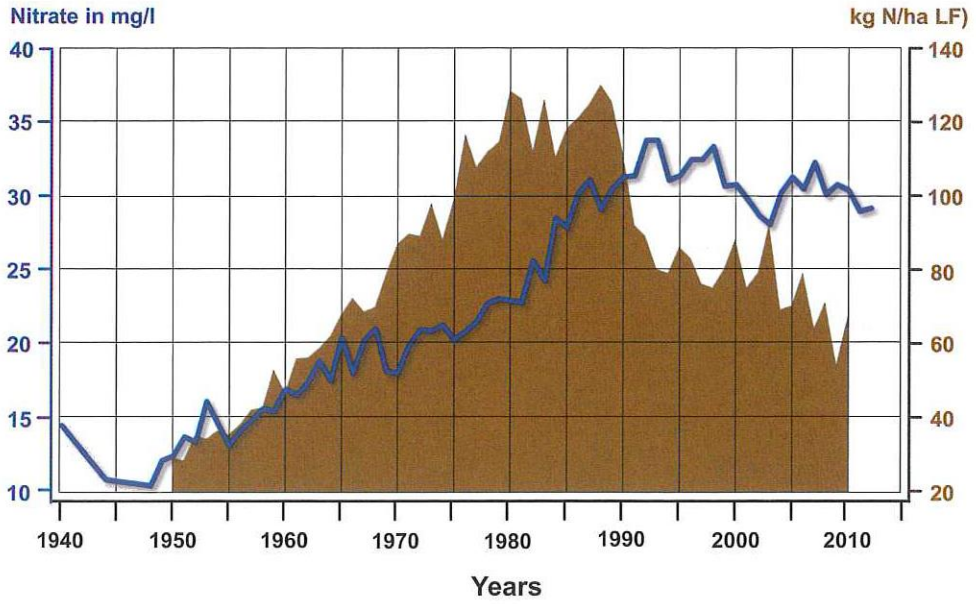
Improving nitrogen efficiency

Not all imported nitrogen is incorporated into biomass

→ In some areas manure application is not fertilization but rather disposal



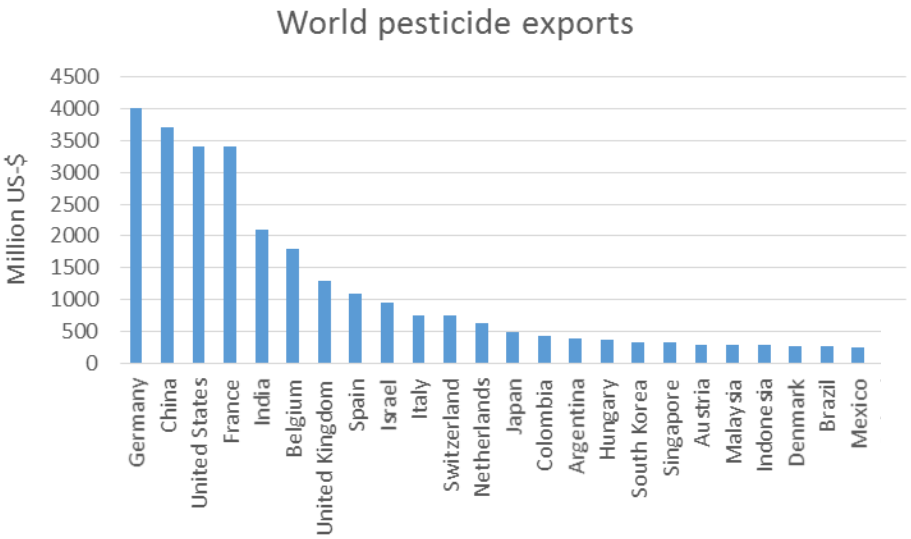
Source: Scientific Advisory Boards for Agricultural Policy (WBA) and Fertiliser Issues (WBD) at the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV); German Advisory Council on the Environment: Opinion on Amendment of the Fertiliser Application Ordinance; 08/2013; page 8

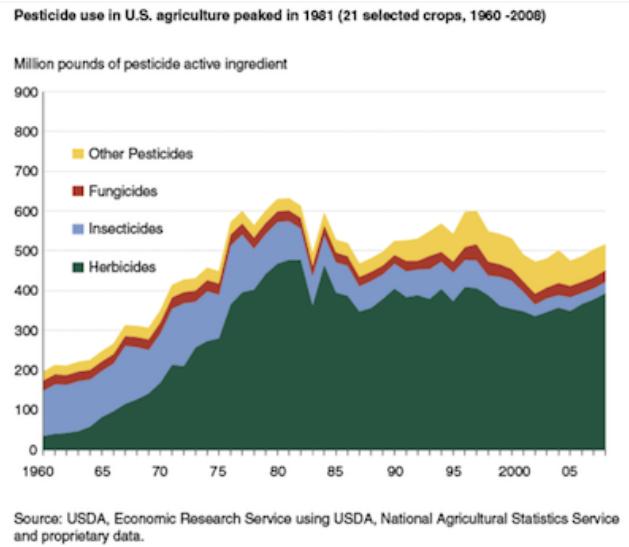


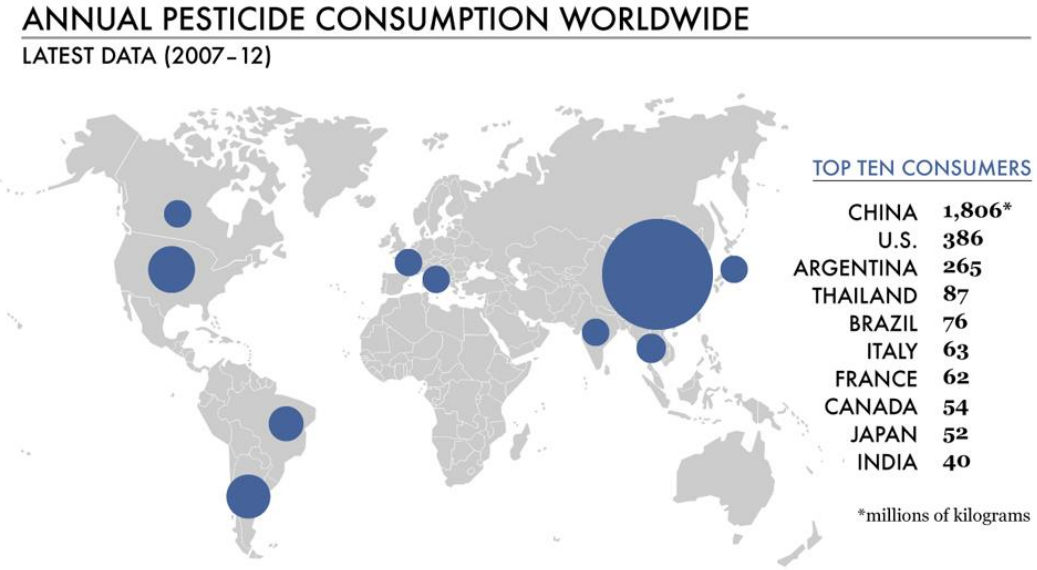
Source: Nitrates Report BRD 2012

Pesticides

world exports







Global market: 44 billion US-$

Source: WTEx, Our World in data, Ensia

Summary

- Agriculture is main driver for landuse change
- Deforestation usually increases groundwater recharge
- Irrigation demand often outcompetes increased recharge

  → overexploitation of gw resources in arid regions common
- Agriculture is a major energy consumer (directly, indirectly)
- German soy imports require a country the size of Paraguay
- Necessary: improved nitrogen efficiency to minimize impacts in producing and importing countries

What can we do?

Farmers

- Improve efficiency in exporting countries (irrigation, pesticides, fertilizer)
- Improve nitrogen efficiency in importing countries

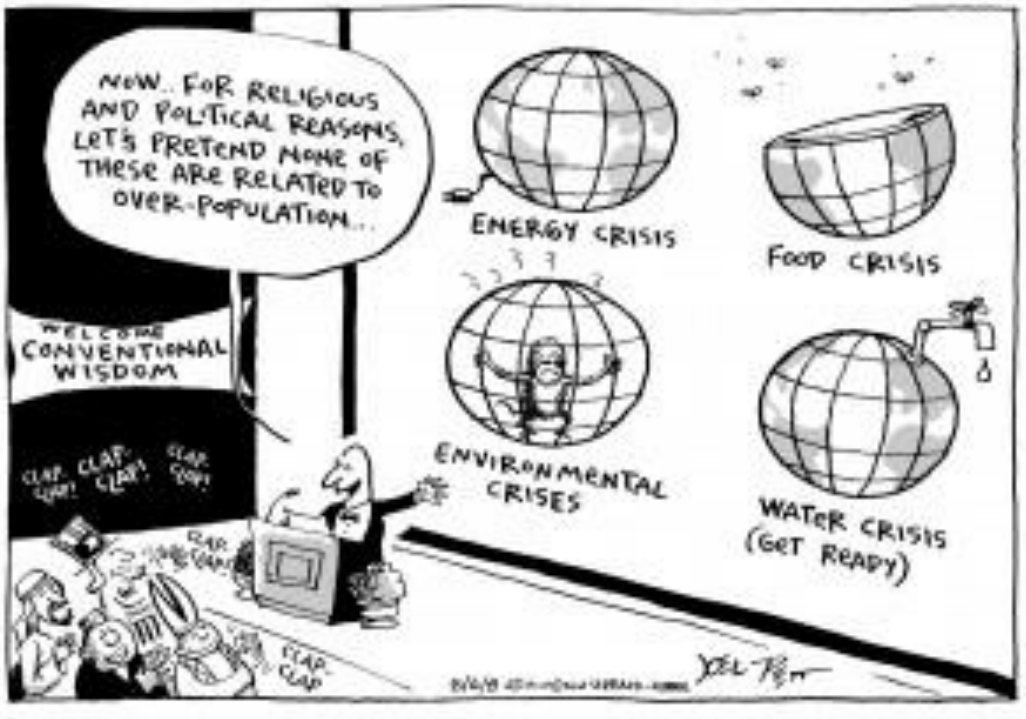
Consumers (that means you and me)

- Minimize food waste
- Eat food with low (water) footprint
- Eat less meat (and better, local meat or that of N-efficient animals)
- Eat local food, if possible
- Avoid out-of-season consumption
- …

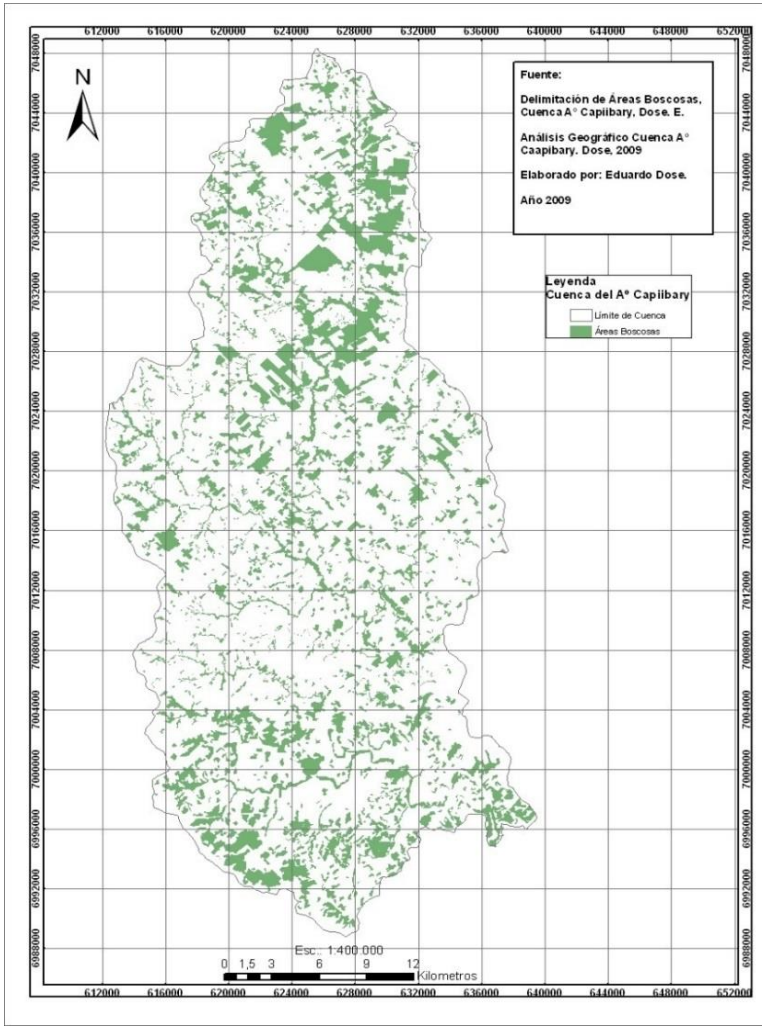
All: think about population growth

Thank you for your attention!

Questions welcome!



The capiibary catchment, SE Paraguay

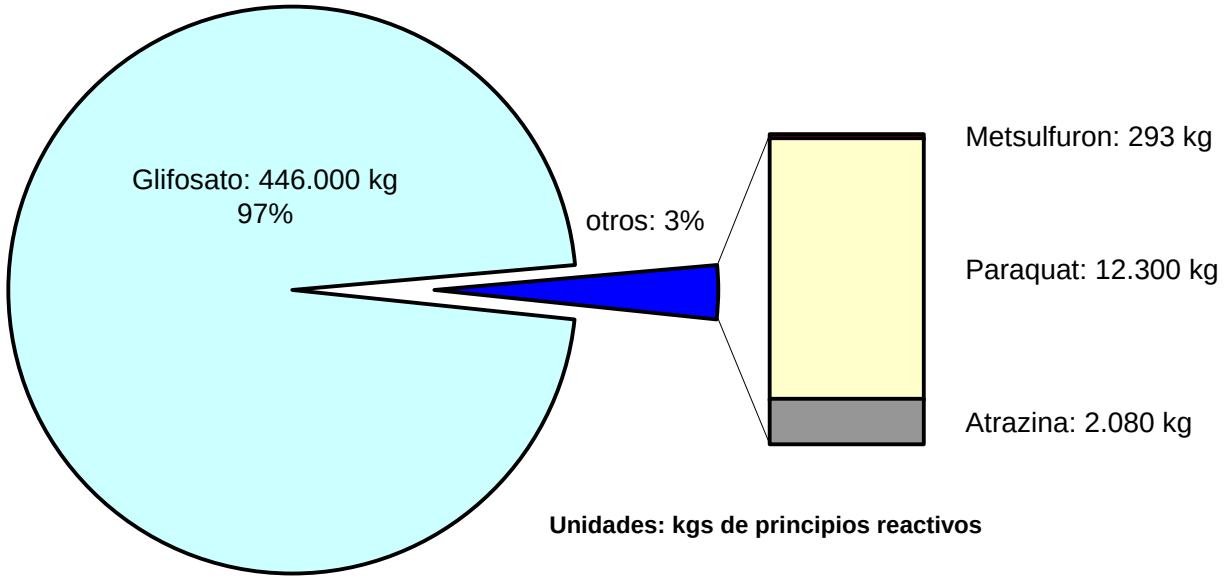


Capiibary catchment (970 km²)

Typical agricultural catchment

- remaining forest cover: 20%
- intensive farming
- 2 to 3 harvests per year
- mostly export cash crops
- soy bean, wheat, corn, sorghum…
- crop rotation
- 99% no-till agriculture
- highly mechanized
- strong agricultural cooperative

Example Capiibary: pesticide application



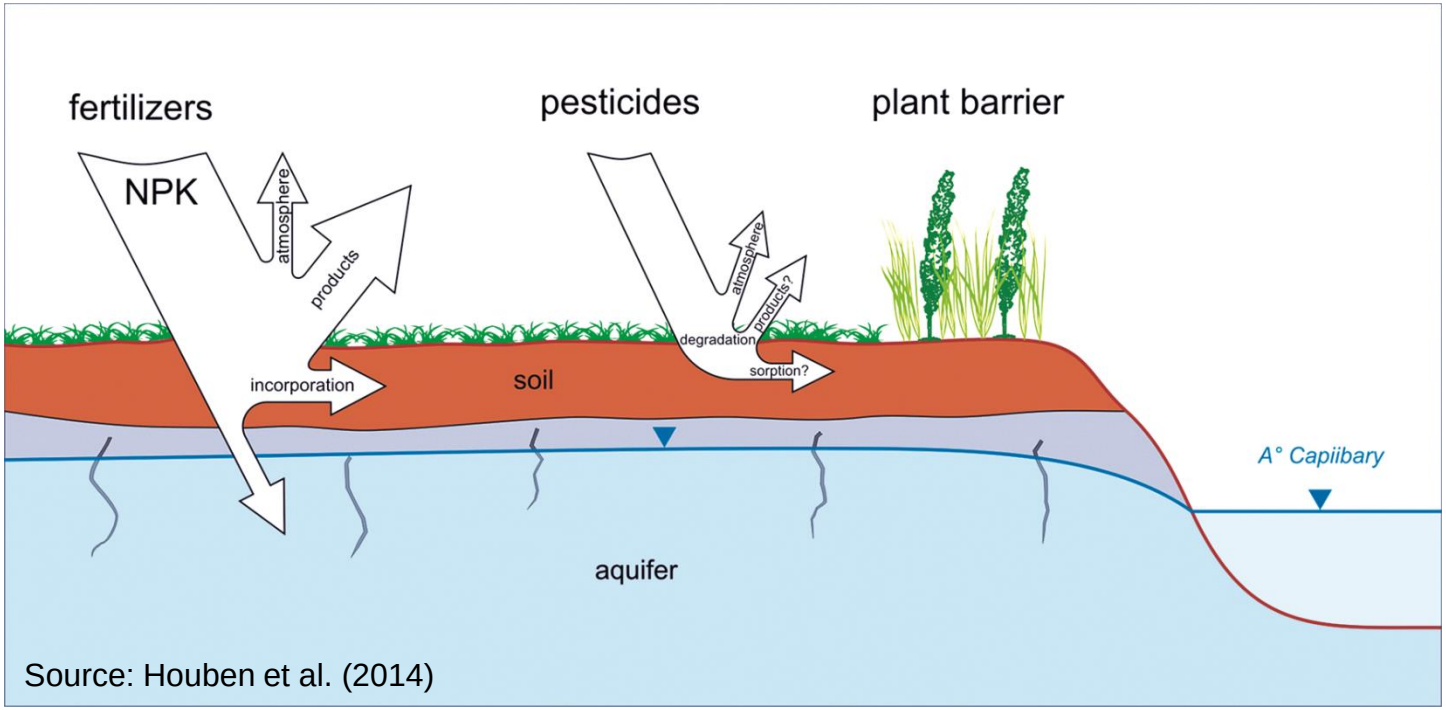
Insecticide: ca. 13.000 l/a
Fungicides: ca. 25.000 l/a
Disadvantage of no-till agriculture: herbicide application needed for all crops, mainly glyphosate (*roundup)*

- ❖ application 2 to 3 times per year
- ❖ dosis: about 2 to 3 l/ha

Capiibary: ground and surface water contamination?

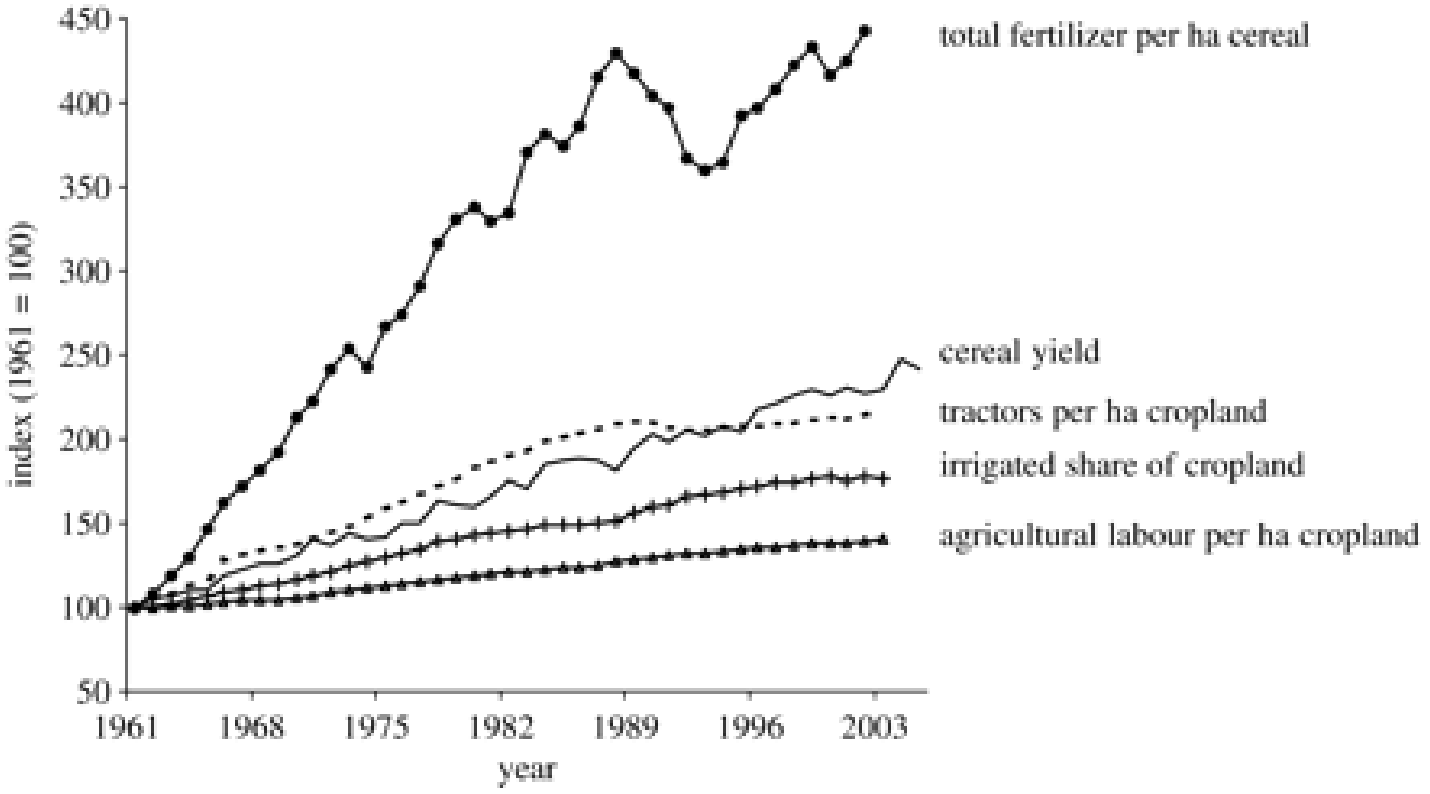
Despite intensive fertilization and pestizide application: low nitrate concentrations and no pesticides found in groundwater and surface water

- subtropical climate → constant activity soil microorganisms (nutrient recycling)
- soils have high sorption potential (high humus and clay content)
- no-till agriculture → organic carbon enrichment, prevention of soil erosion
- awareness & training of farmers: plant barriers, pesticide filling & cleaning stations



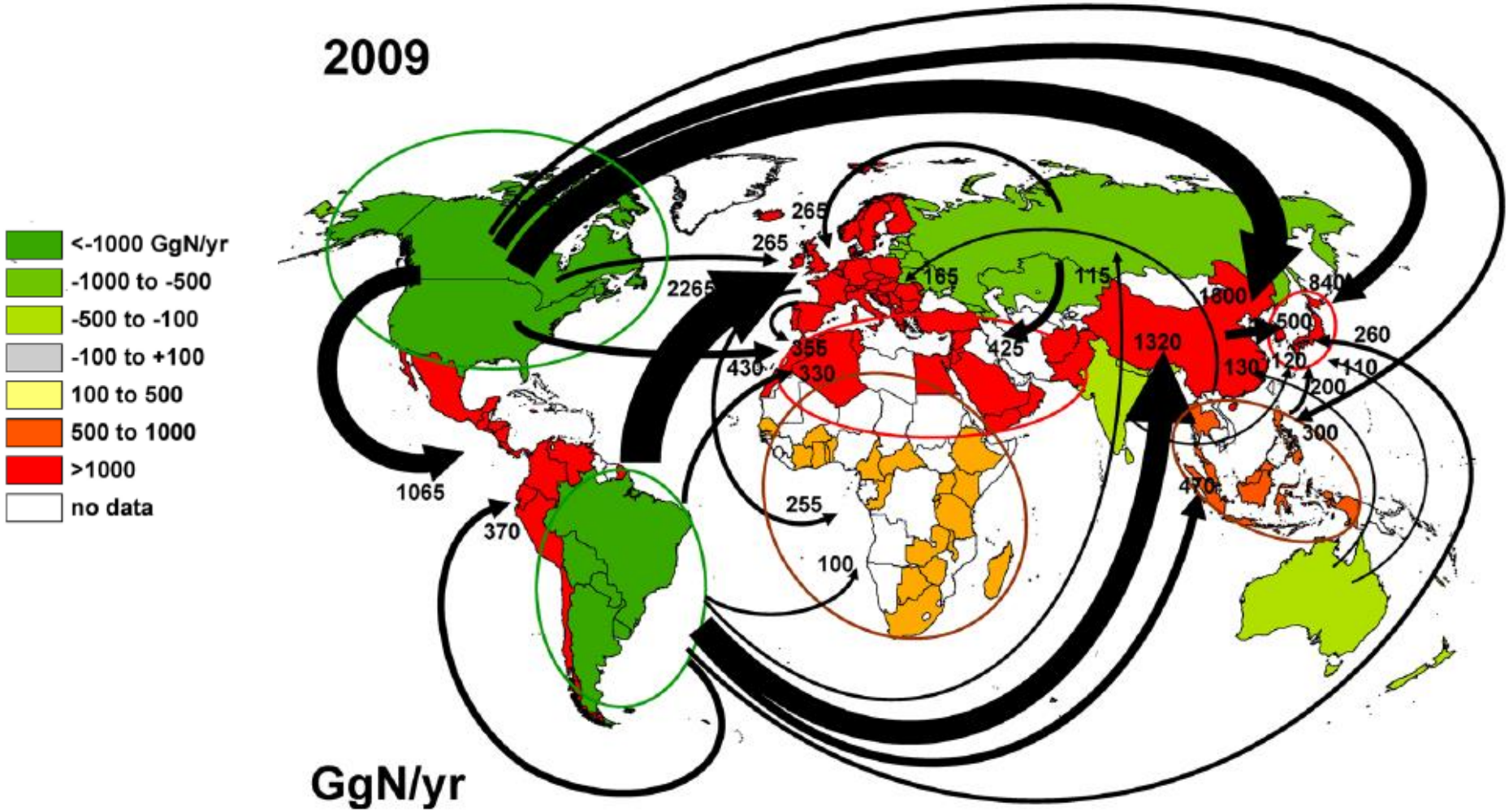
Source: Houben et al. (2014)

How blue is the green revolution?



(Hazell and Wood 2008)

Global N cycle: importing air

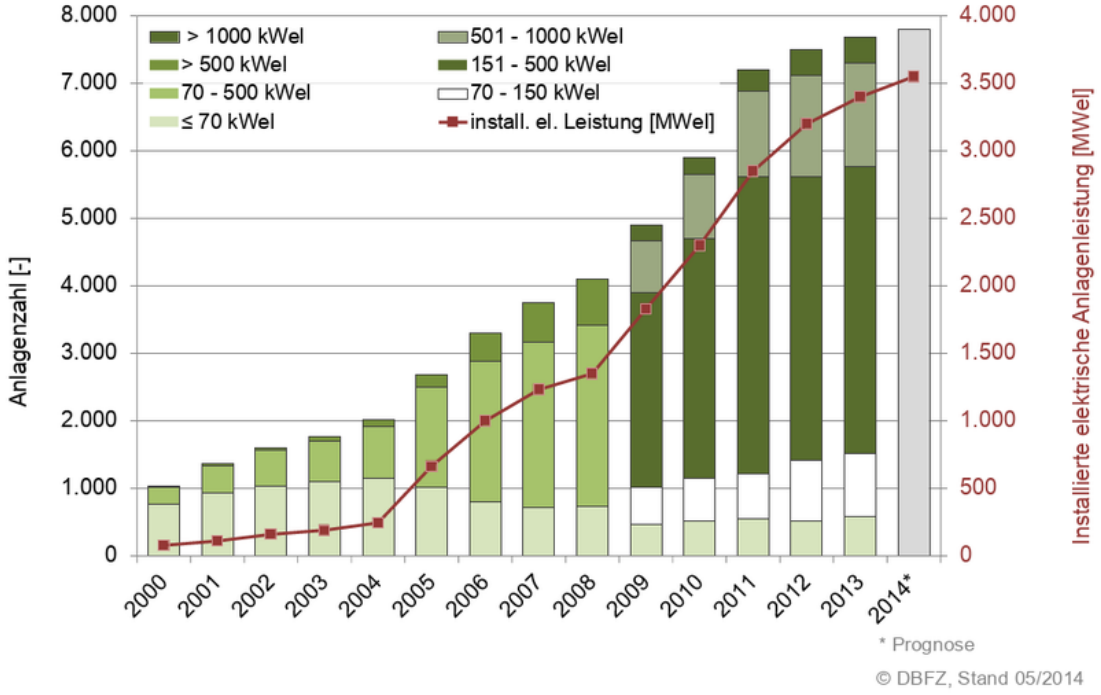


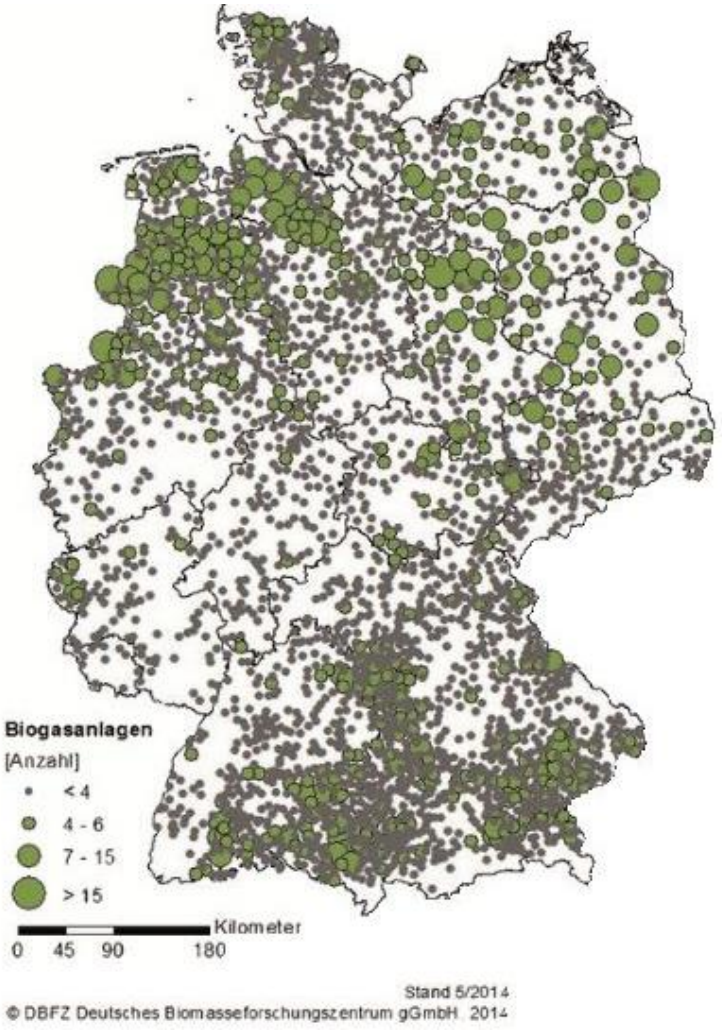
Lassaletta et al. (2014)

Biogas: a good idea gone bad (1)

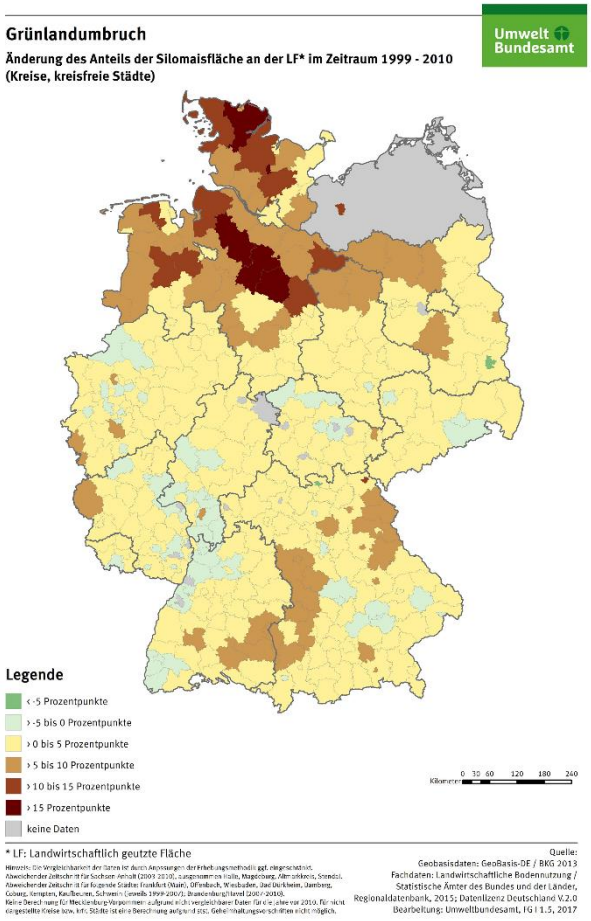
Idea use agricultural residues to produce biogas → clean energy

Reality farmers plant crop specifically for biogas, convert pasture into arable land → nitrate release to groundwater





Biogas: a good idea gone bad (2)



<u>Reality</u> farmers plant crop specifically for biogas: apply high manure loads convert pasture into arable land

→ nitrate release to groundwater