Soil degradation, land scarcity and food security:

Reviewing a complex challenge

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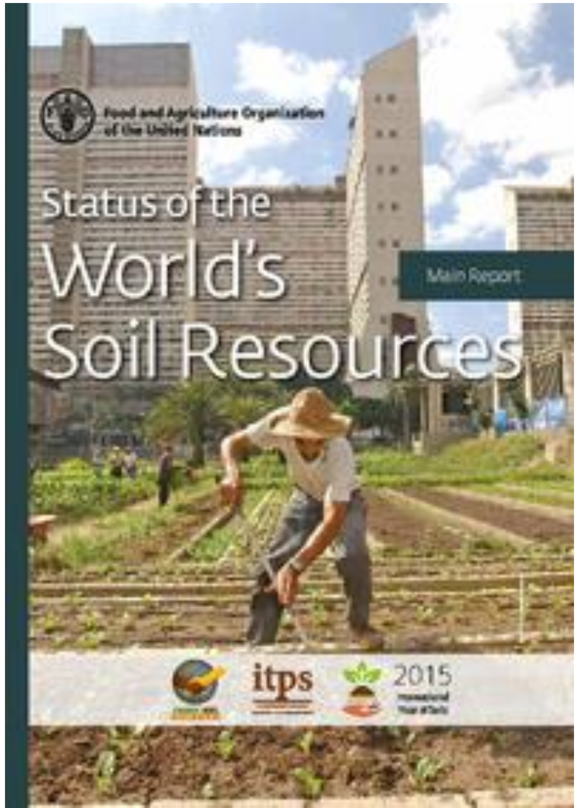
MU University – 1 March 2016

Gomiero, Soil degradation, land scarcity and food security: Reviewing a complex challenge

Paper in press on *Sustainability* (http://www.mdpi.com/journal/sustainability)

The 68th UN General Assembly declared 2015 the International Year of Soils (IYS)

The UN stated that "…*soils constitute the foundation for agricultural development, essential ecosystem functions and food security and hence are key to sustaining life on Earth*".



Objectives of the IYS 2015

- Raise full awareness among civil society and decision makers
- Educate the public
- Support effective policies and actions for the management and protection of soil resources;
- Promote investment in sustainable soil management activities
- Advocate for rapid capacity enhancement for soil information collection and monitoring at all levels (global, regional and national).

http://www.fao.org/soils-2015/resources/fao-publications/en/

FAO
Soil portal
http://www.fao.org/soils-portal/soil-degradation-restoration/en/
Soil Atlas: Facts and figures about earth, land and fields
http://www.boell.de/en/2015/01/07/soil-atlas-facts-and-figures-about-earth-land-and-fields
Status of the World's Soil Resources
http://www.fao.org/soils-2015/resources/fao-publications/en/
http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/

UN – 2015, Year of the soils
http://www.un.org/apps/news/story.asp?NewsID=49520

EC-JRC
Soil portal
http://eusoils.jrc.ec.europa.eu/library/themes/erosion/

USDA
Soil portal
http://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/
Soil Survey Manual
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/scientists/?cid=nrcs142p2_054262

Soil and soil degradation: Definitions and typologies

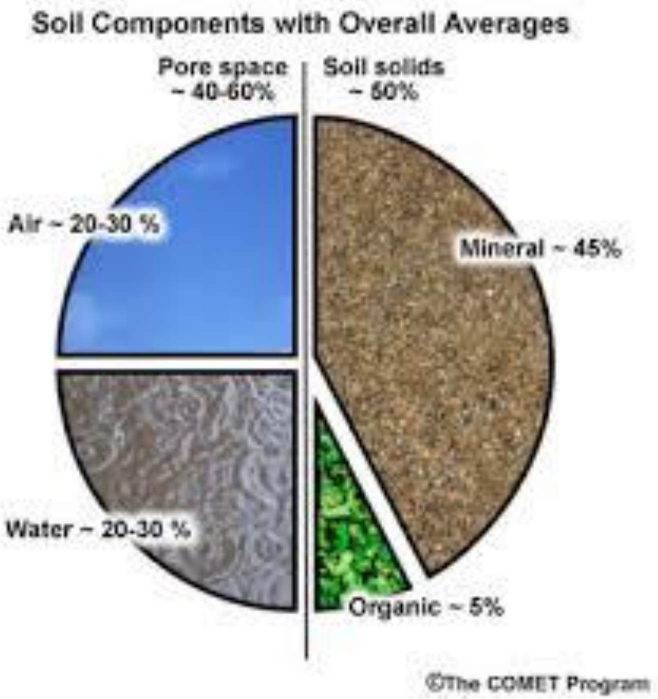
Can we feed the world?

Soil and human pressure: trends and issues

Soil is defined as the top layer of the Earth's crust.

It is a natural substance composed of weathered rock particles (minerals), organic matter, water and air.

FAO defines **soil degradation** "… *as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem*".



http://www.fao.org/soils-portal/soil-degradation-restoration/en/

Soil degradation: tipologies

Agricultural activities

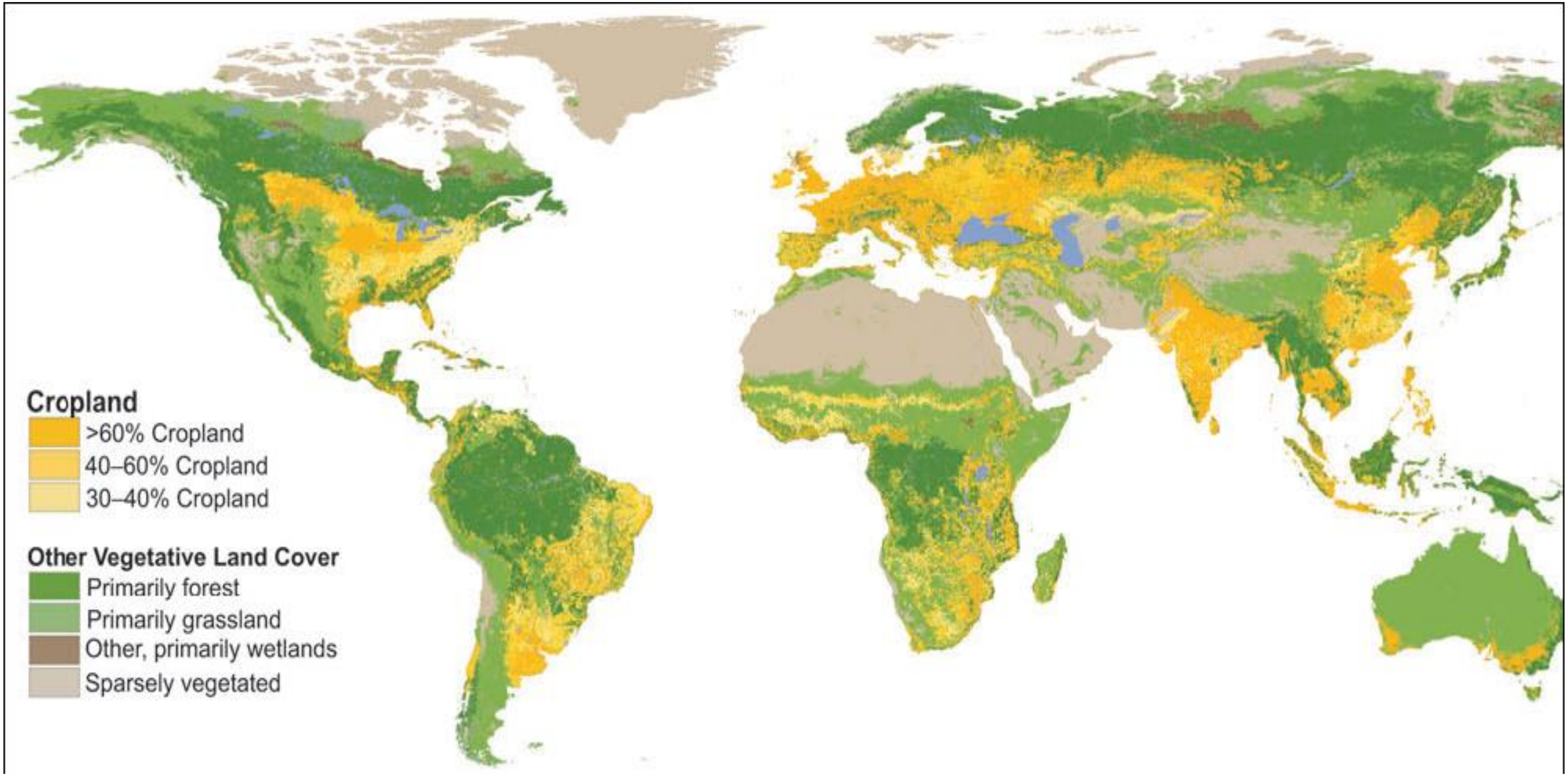
- Loss of soil organic matter
- Erosion
- Compaction
- Salinization
- Contamination (e.g., agrochemicals)
- Loos of biodiversity

Other human activities

- Contamination (e.g., waste disposals, indutry)
- Sealing (urbanization)

Land degradation - The cropped planet

Of the global land area of 13.2 billion ha, 12% (1.6 billion ha) is currently in use for the cultivation of agricultural crops, 35% (4.6 billion ha) comprises grasslands and woodland ecosystems, and 28% (3.7 billion ha) is forested (FAO, 2011a



Over the last 50 years:

- the world's net cultivated area has grown by 12%,
- the global irrigated area has doubled (FAO, 2011a).

Tropical forests represented about 30% of new agricultural land;

- 55% is represented by intact forest
- 25% by disturbed forest (Gibbs et al., 2010).

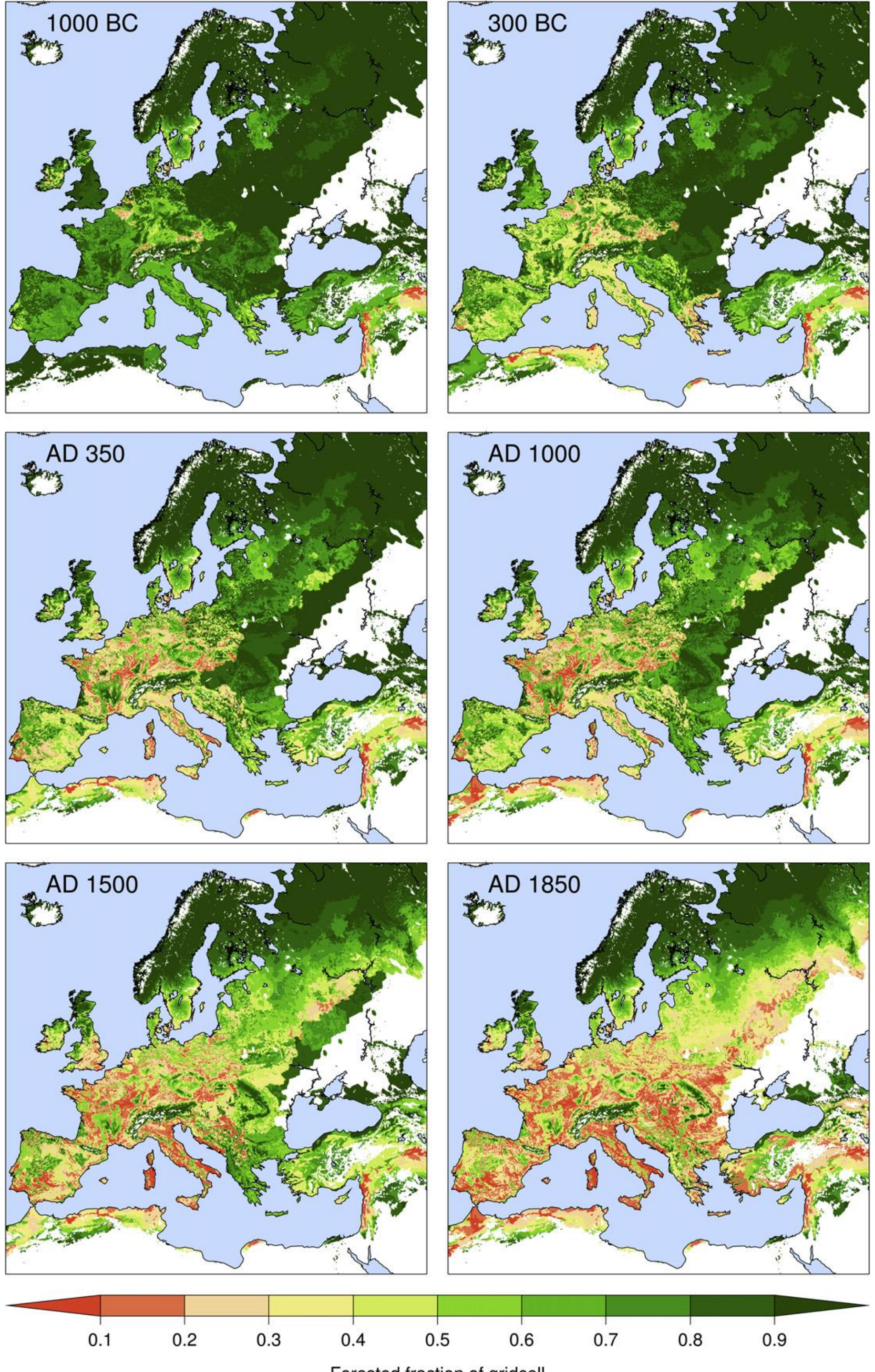
In the past 50 years the population has grown by 110% and cropland by only 10-12% may be telling figures pointing to the fact that there is not much land that can be easily cropped (Conway, 2012) .

The expansion of soybean (300%) and palm oil (700%) is presumably due to the clearing of the Cerrado in Brazil and the rain forests in many tropical countries

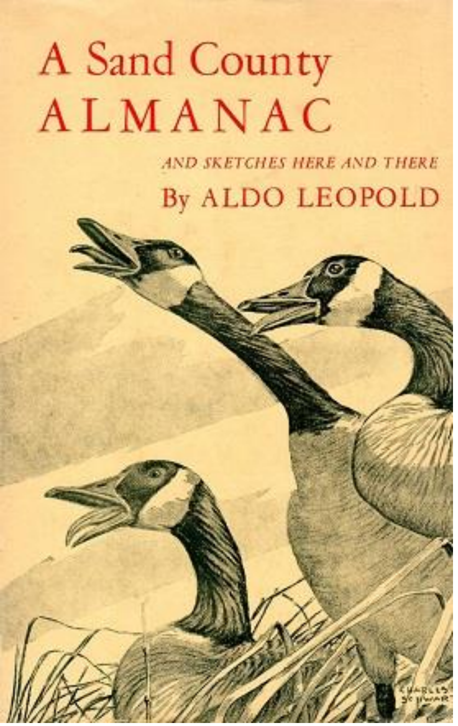
Forest resources and deforestation in the humid tropic in the 1980s, (data from Jepma, 1995).

	Forest area estimates			Average annual deforestation					
	WRI	**FAO**	**Myers**	**WRI**		**FAO**		**Myers**	
	Mha	Mha	Mha	Mha	%	Mha	%	Mha	%
Latin America	785,875	823,500	389,950	10,918	1.4	5,274	0.6	6,650	1.7
Africa	463,928	349,239	52,200	2,430	0.5	2,616	0.7	1,580	1.0
Asia	272,826	234,039	194,100	2,751	1.0	3,219	1.4	4,200	2.2
Total	1,522,629	1,406,778	636,250	16,049	2.9	11,209	2.7	13,430	4.9

Cropping Europe



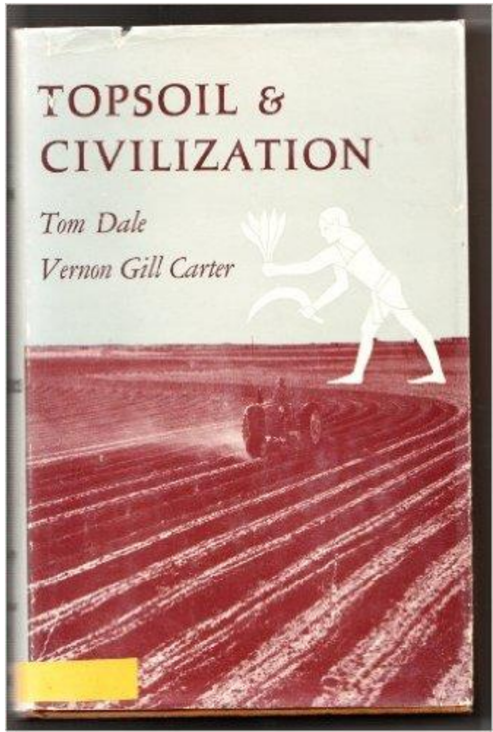
Kaplan et al., Quaternary Science Reviews 28 (2009) 3016–3034



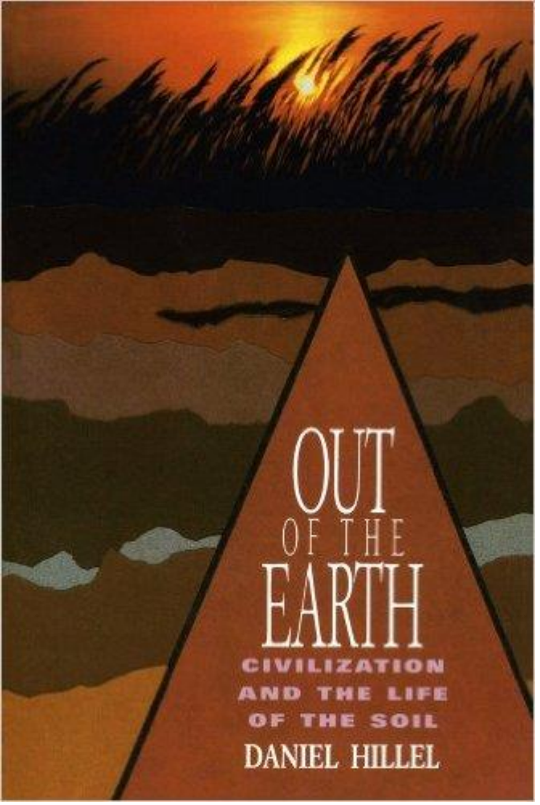
“*One basic weakness in a conservation system based wholly on economic motives is that most of the members of the land community have no economic value*” (Leopold, 1949, p. 210).

“... assuming that the economic parts of the biotic clock will function without the uneconomic parts” (Leopold, 1949, p. 214).

(Leopold, 1949, p. 226). Two major obstacles to the evolution of a land ethic: (1) “…*the fact that our educational and economic system is headed away from, rather than toward, an intense consciousness of land*”. (2) “…*attitude of the farmer for whom the land is still an adversary, or a taskmaster that keeps him in slavery*”.



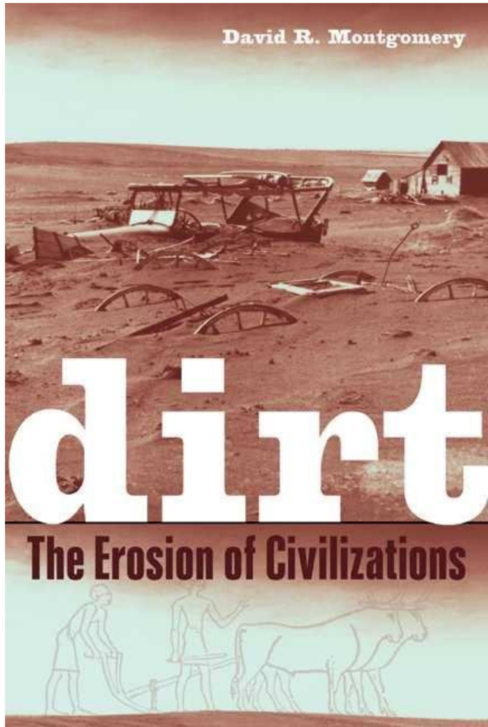
Dale and Carter (1955), land scarcity was the main trigger to war and colonization; however, it is often overlooked that the conquerors or colonizers ruined their own land before undertaking their expansive actions.



Hillel (1991), very often a land shortage is due to poor land management rather than to any fundamental scarcity of resources. "*We cannot continue to subsidize or even tolerate practices that cause erosion, salinization, and ground water contamination and depletion, or policies that make poor nations permanently dependent on the largesse of their rich neighbors*"

"*Soil is our most underappreciated, least valued, and yet essential natural resource.*"

"*Modern society fosters the notion that technology will provide solutions to just any problem. But no matter how fervently we believe in its power to improve our lives, technology simply cannot solve the problem of consuming a resource faster than we generate it: someday we will run out of it*". Montgomery (2007)

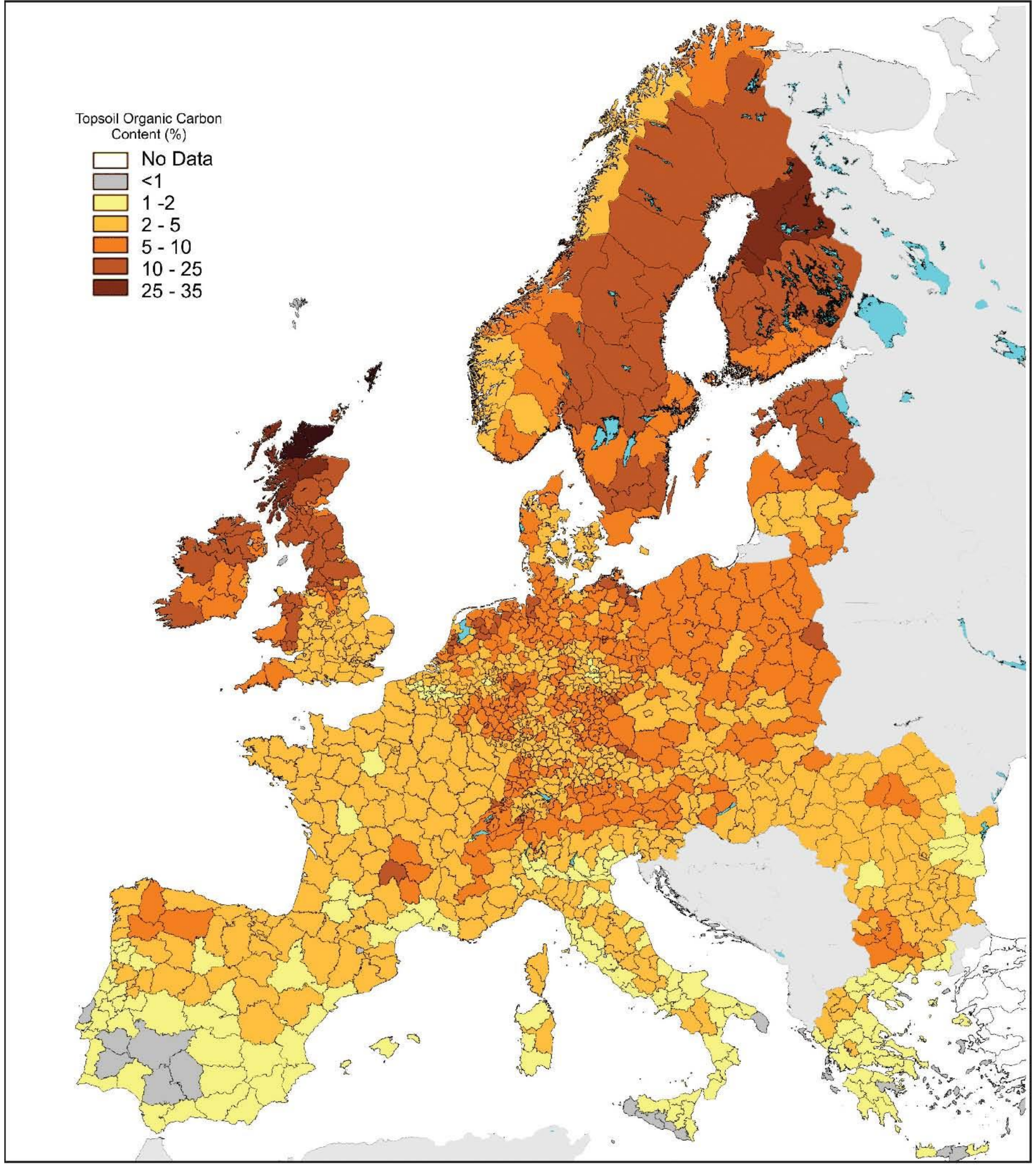


Organic matter decline

Organic matter is a key component of soil, controlling many vital functions.

State of soil organic carbon levels:

- Around 45% of the mineral soils in Europe have low or very low organic carbon content (0–2%)
- 45% have a medium content (2–6%)
- 74% of the land in southern Europe is covered by soils that have less than 2% of organic carbon in the topsoil (0–30cm)



The map above shows the distribution of soil organic carbon, a major component of organic matter, according to administrative units; it emphasises the generally low levels in southern Europe compared to the north (RH).

Erosion

Erosion is a process of soil degradation that occurs when soil is left exposed to rain or wind energy. Loss of topsoil and nutrients content.

Under natural conditions,

0.0045 t ha^{-1} yr (moderate relief)

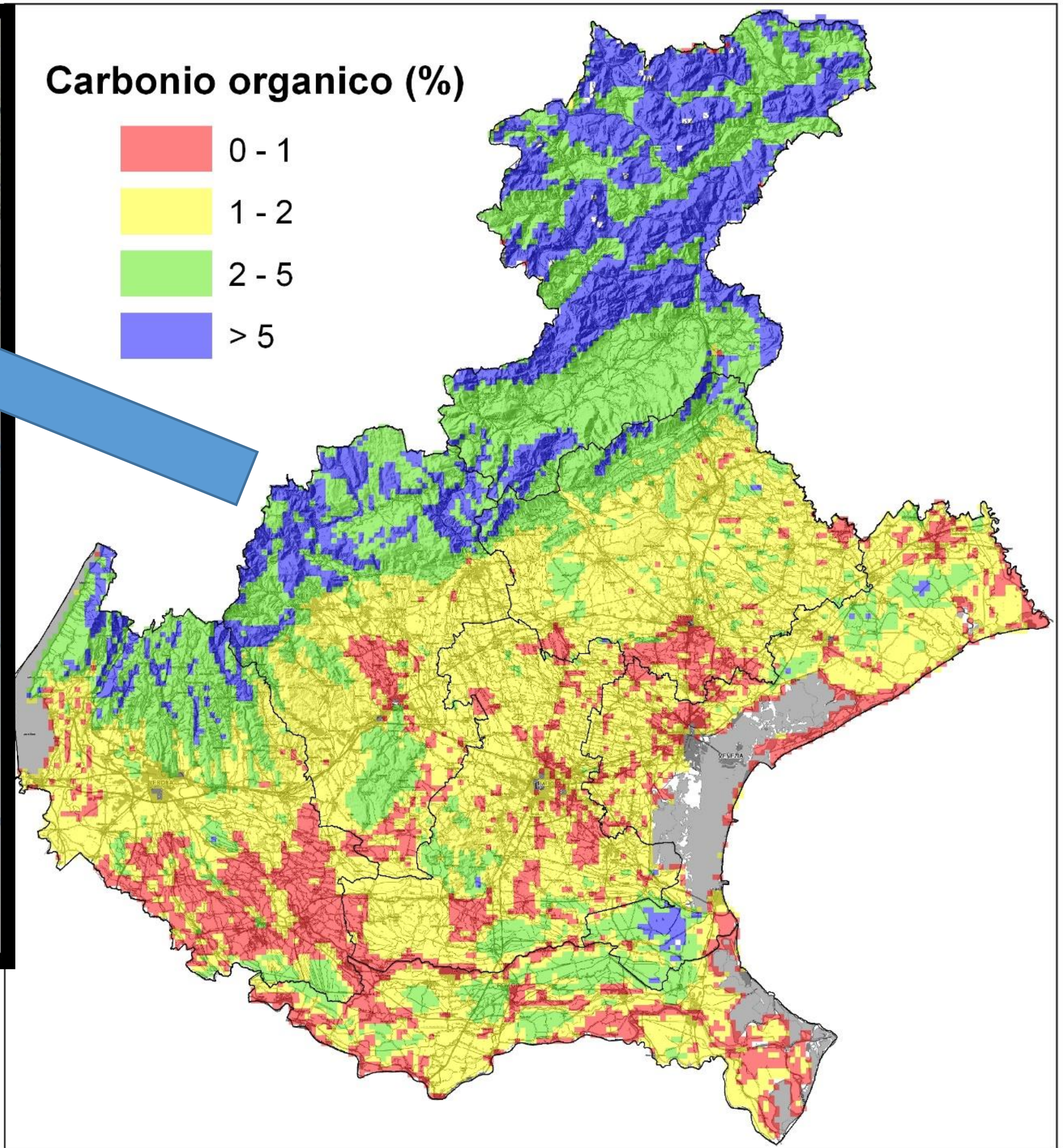
0.45 t ha^{-1} for steep relief.

Agricultural land, 45–450 t ha^{-1}

Soil is lost at 10 to 40 times faster than it is being formed

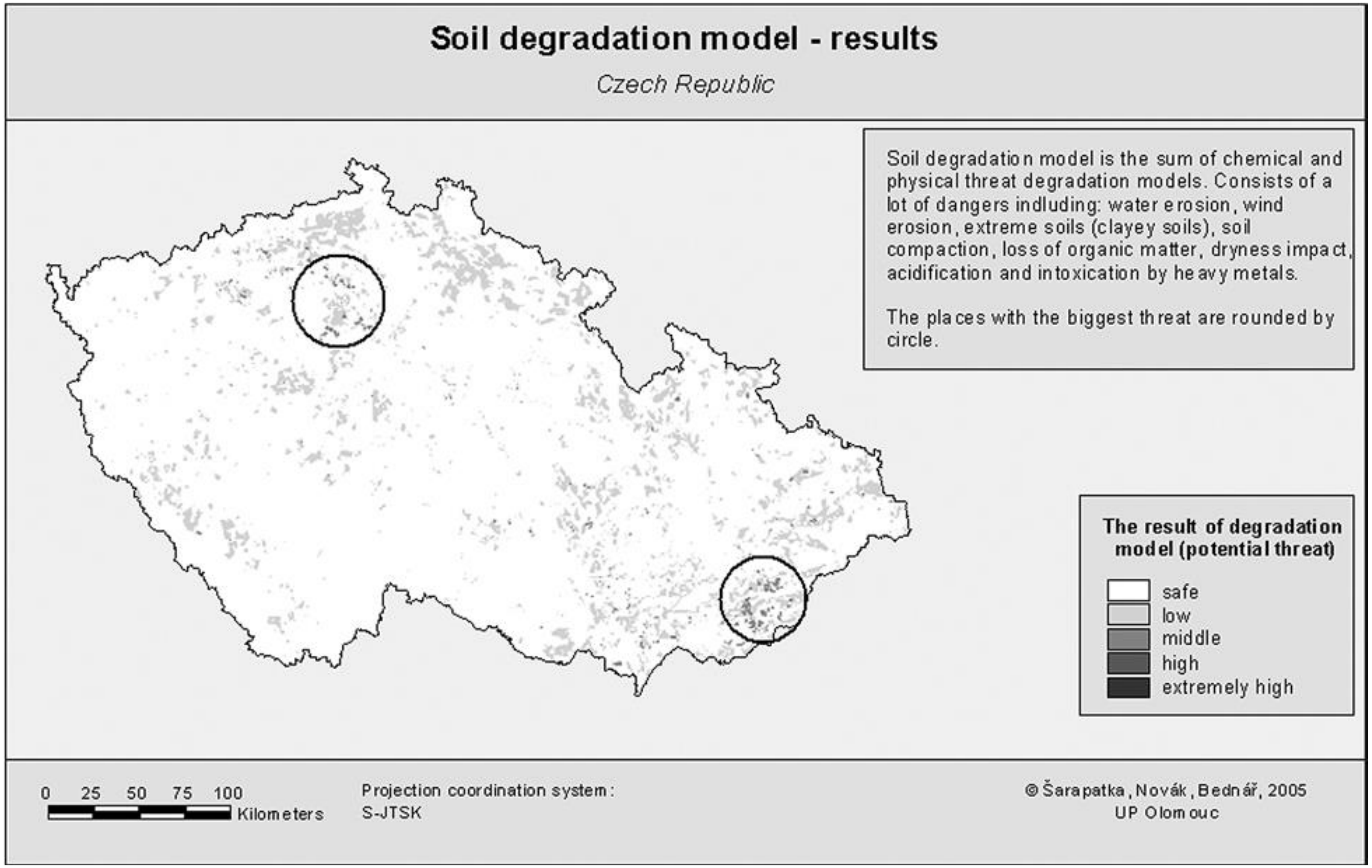
Mild to severe soil erosion may affect 80% of global agricultural land.

%C organic in Veneto, estimates 2010



Soil degradation in Czech Republic

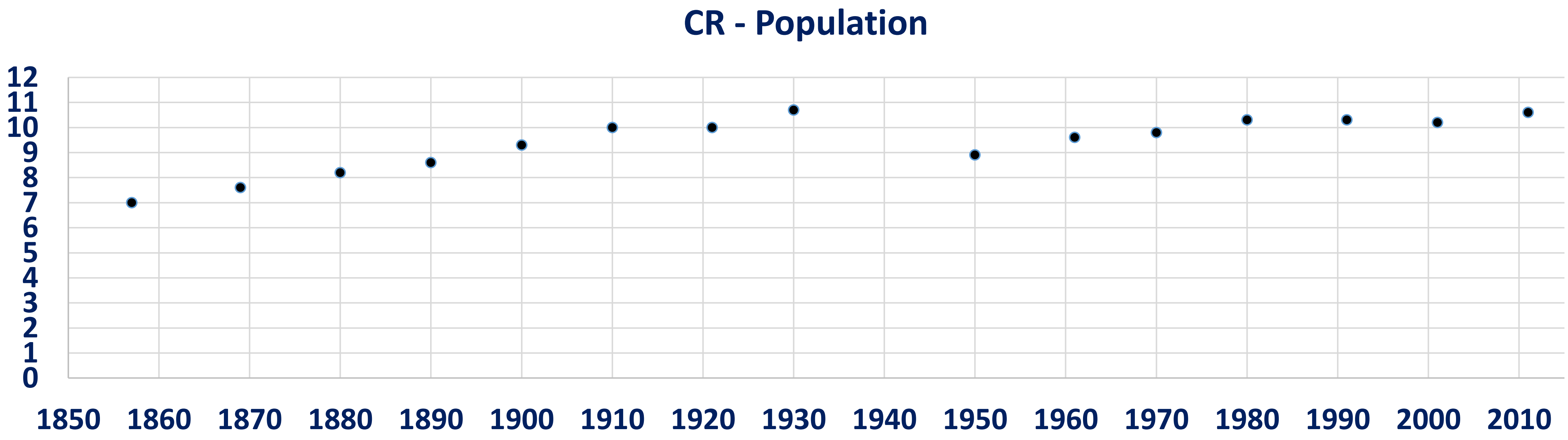
Šarapatka et al., 2010. Soil & Water Res., 5, (3): 108–112 (Palacký University)



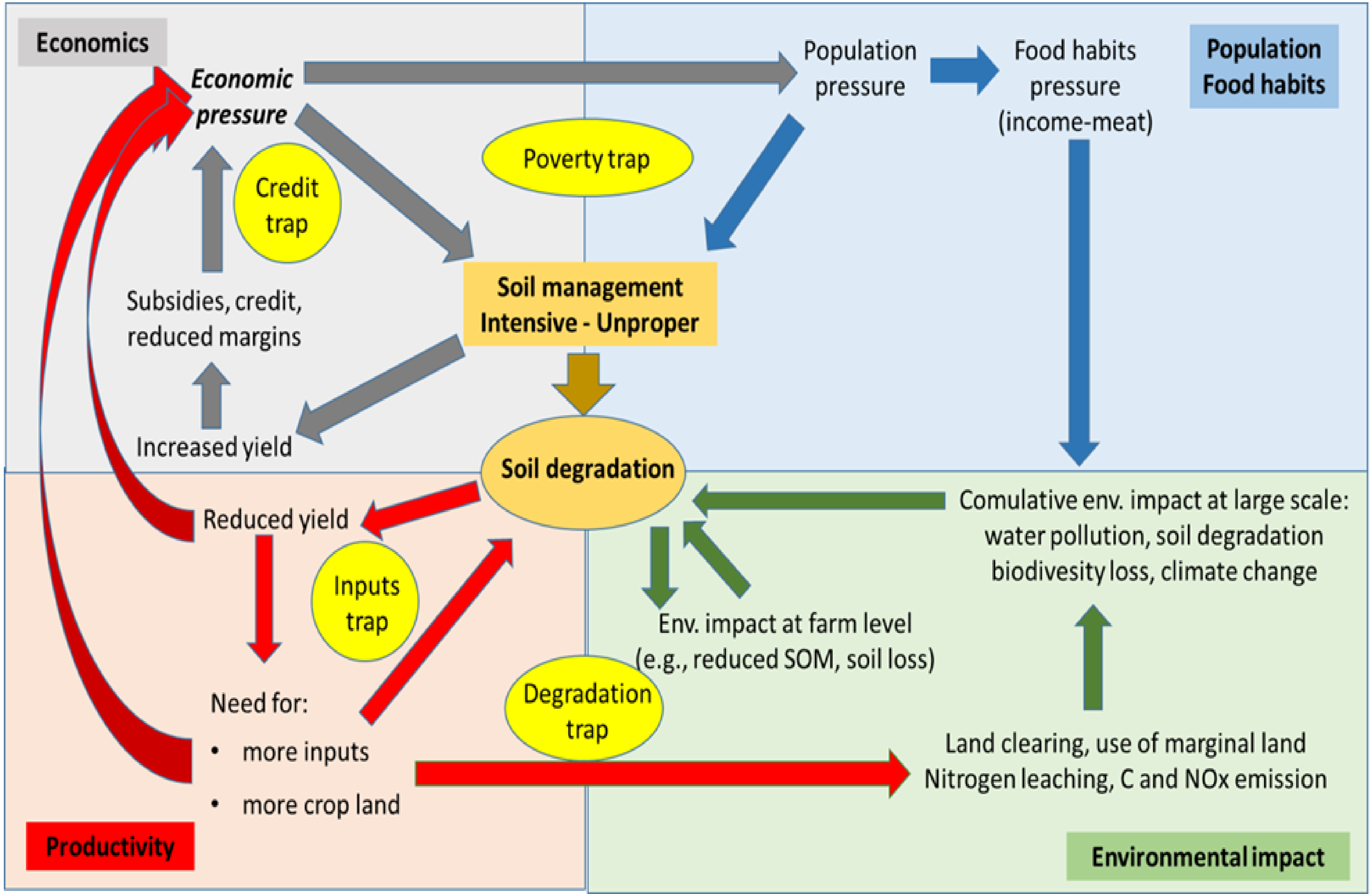
Problem with soil degradation in very intensively used agricultural production areas.

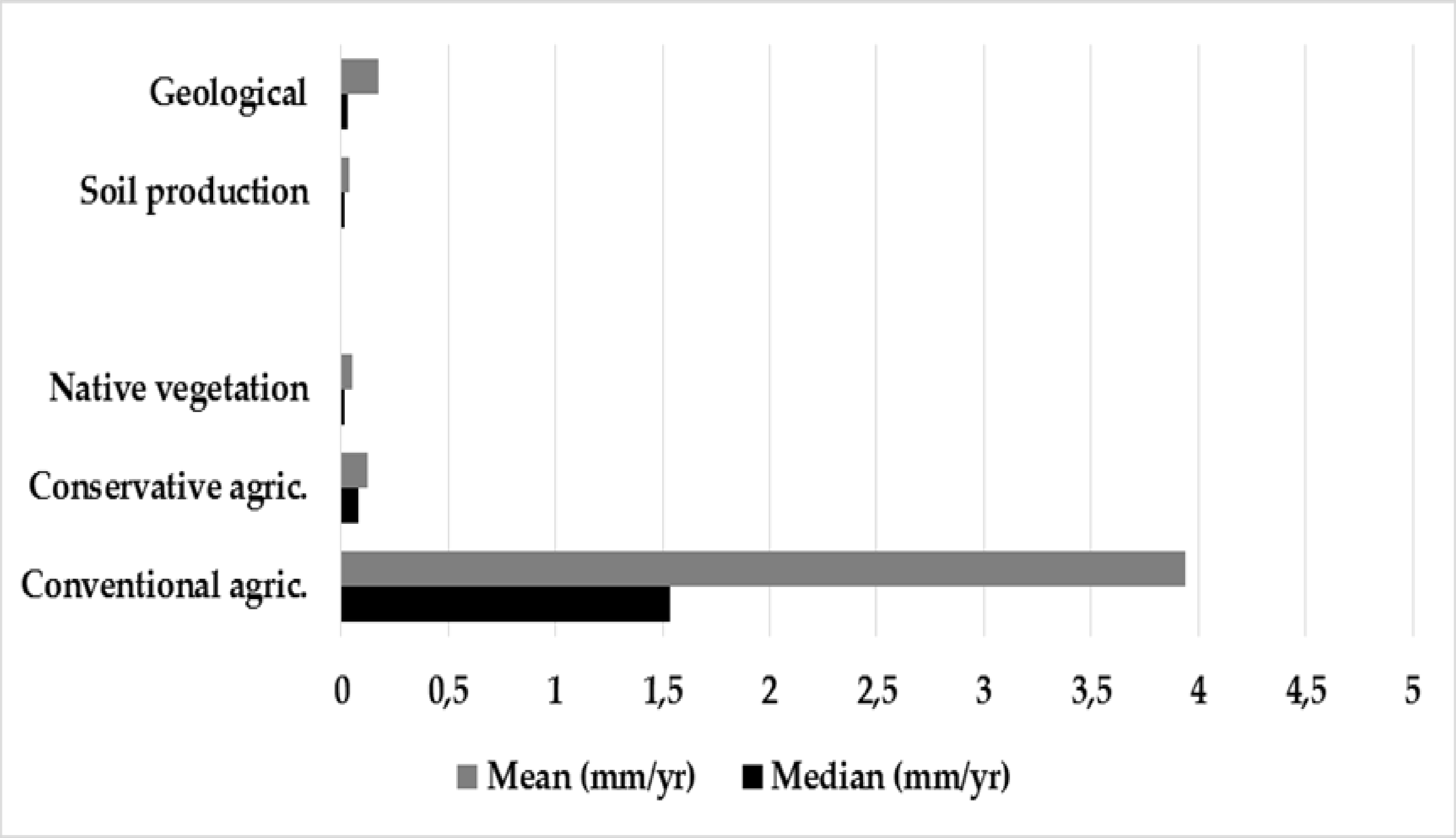
	Land 2010		
Tot. Land (M ha)	Agric. land on tot land (%)	Arable on tot agric land (%)	Arable per capita
3.17	55	41	0.3

% change 2000-2010			
Population	Tot. arable	Arable per capita	GDP
2.1	-2.2	-4.3	230



Complex relations among the different dimensions of the farming system in relation to soil degradation (Gomiero, 2016)



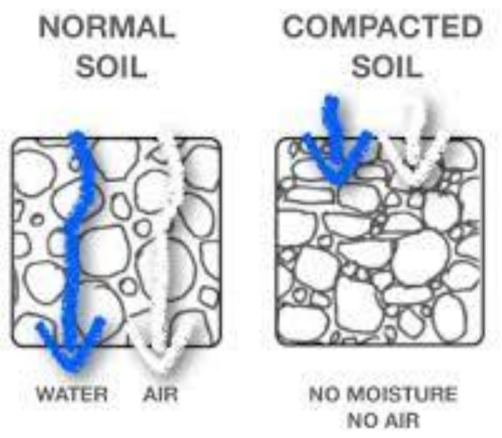


Soil erosion rate for managed and natural soils: result from a meta-analysis (data after Montgomery, 2007b)

Compaction can be induced by the use of heavy machinery in agriculture.

Compaction reduces the capacity of soil to store and conduct water, makes it less permeable for plant roots and increases the risk of soil loss by water erosion.

Estimates of areas at risk of soil compaction vary. Some authors estimate that 36% of European subsoils have a high or very high susceptibility to compaction. Other sources report 32% of soils as being highly susceptible and 18% moderately affected.



Salinisation

It is the result of the accumulation of salts and other substances from irrigation water and fertilisers.

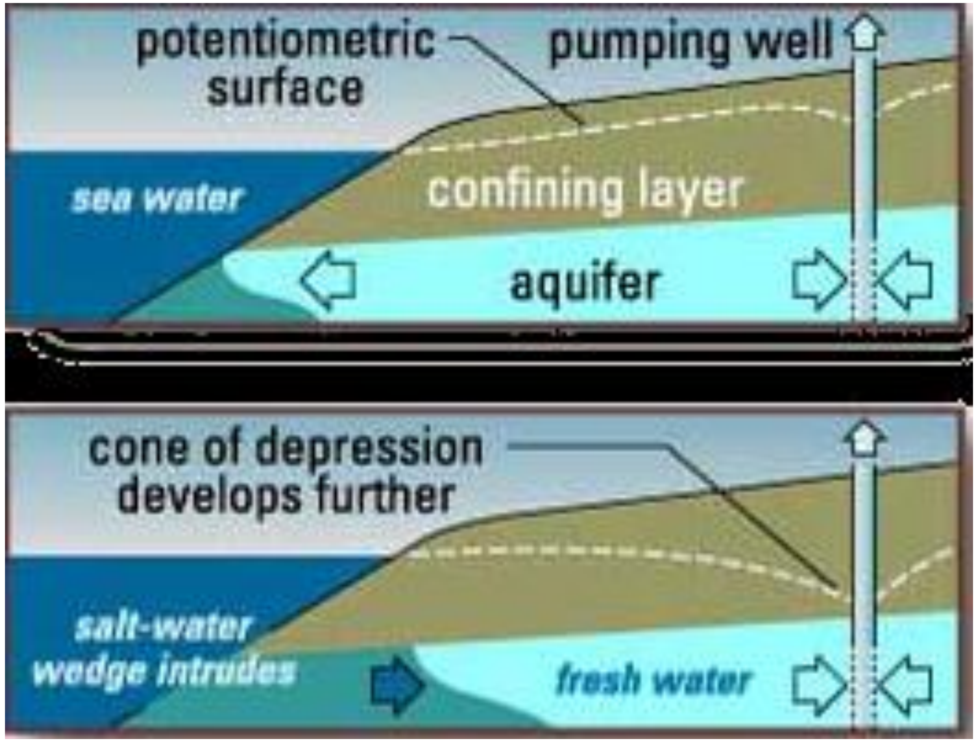
High levels of salt will eventually make soils unsuitable for plant growth.

It affects approximately 3.8 million ha in Europe.

The main driver is the inappropriate management of irrigated agricultural land.

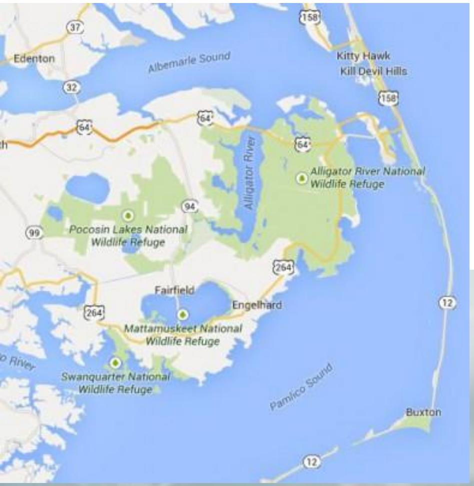
Saltwater intrusion

alteration of the water table (change see-level)

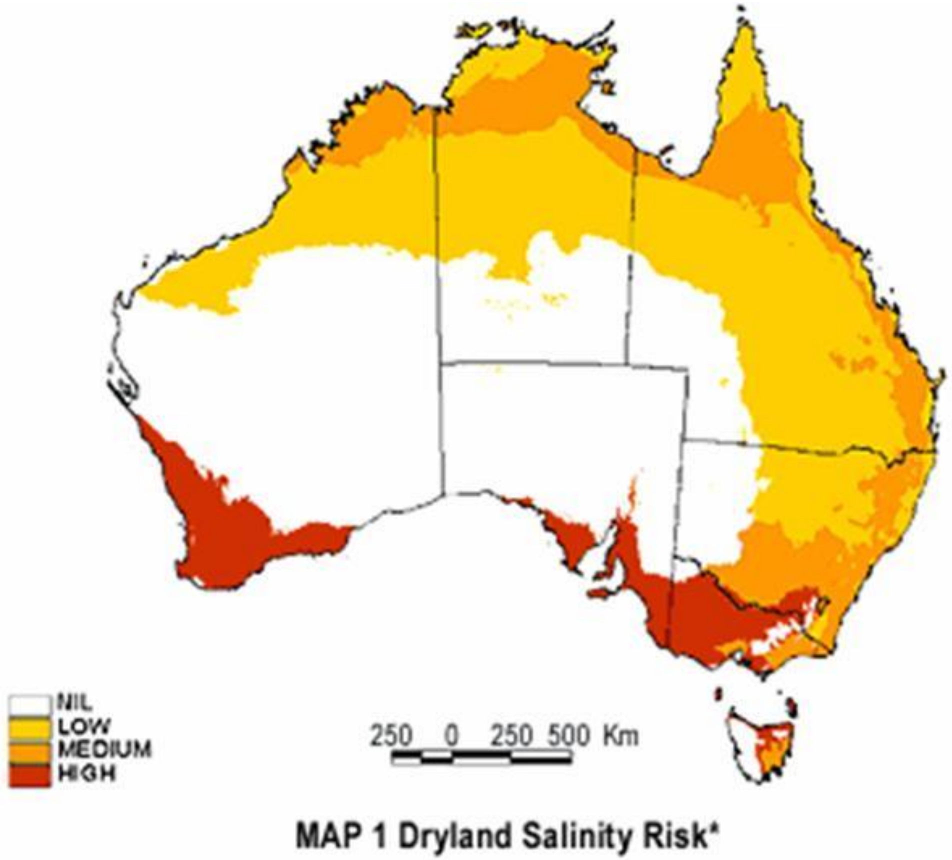


It is estimated 5.7 million hectares of land is at risk of salinitization

This number is expected to rise to 17 million hectares by 2050

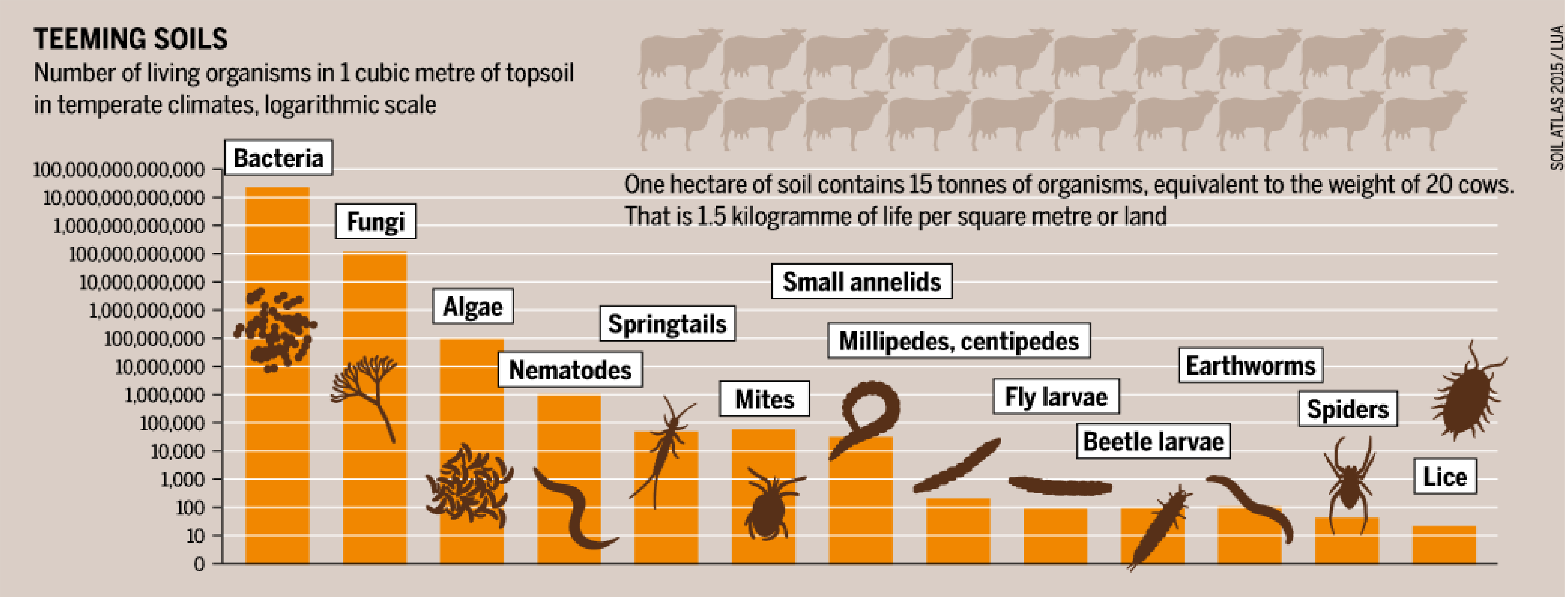


North Carolina Coast



Biodiversity decline

Soil biodiversity reflects the enormous variety of organisms, from bacteria to mammals, which shape the metabolic capacity of terrestrial ecosystems and many soil functions. Soil biodiversity is affected by all of the threats and degradation processes listed below and contribute to the loss of soil biodiversity.



Is technology going to fix it all?

Climate change may increae soil degradation and reduce SOM

BUT

Depleted soil can be fixed by using more fertiliser (and more water and energy) to produce more biomas...

Is this a «solution»?

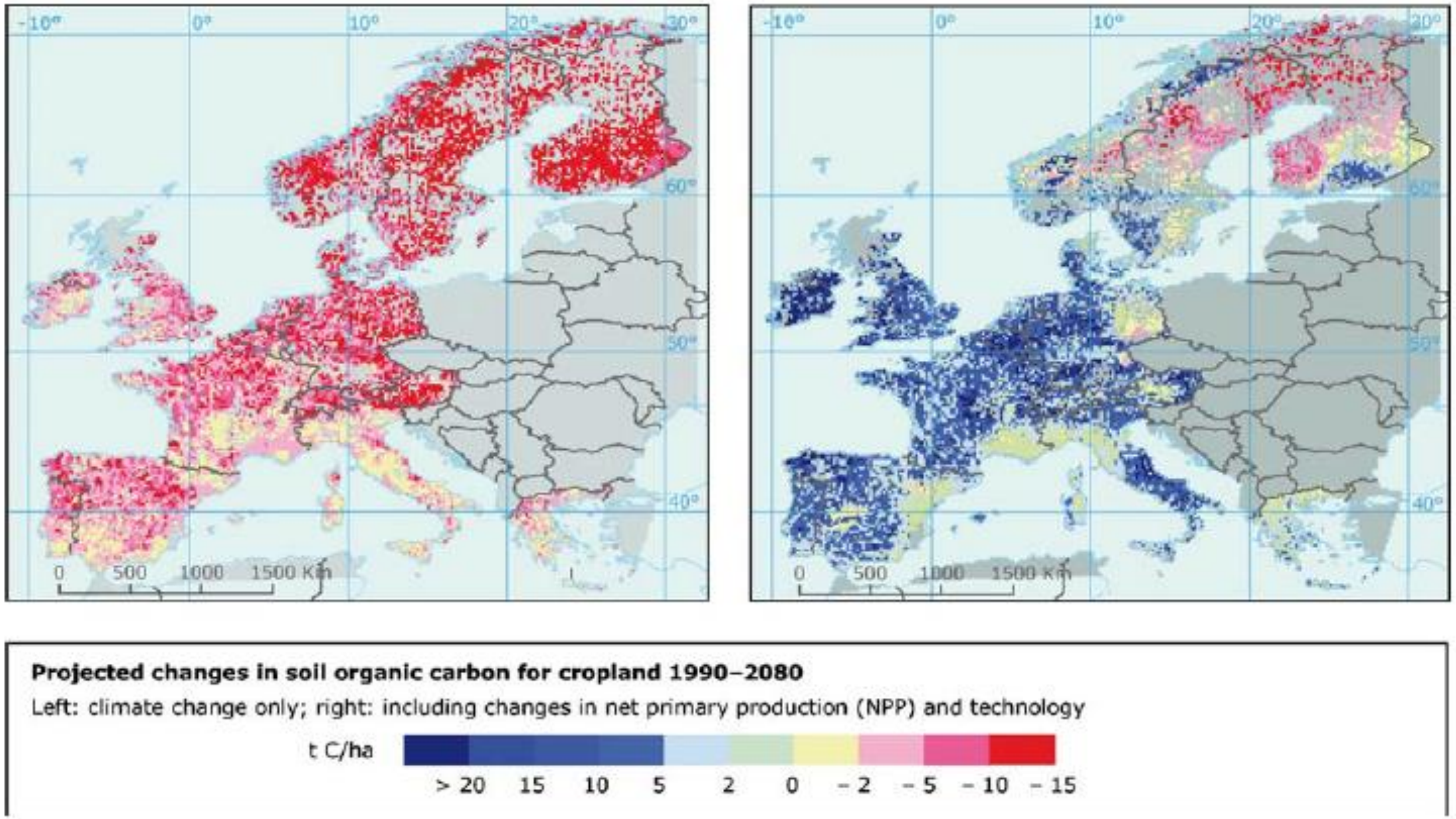
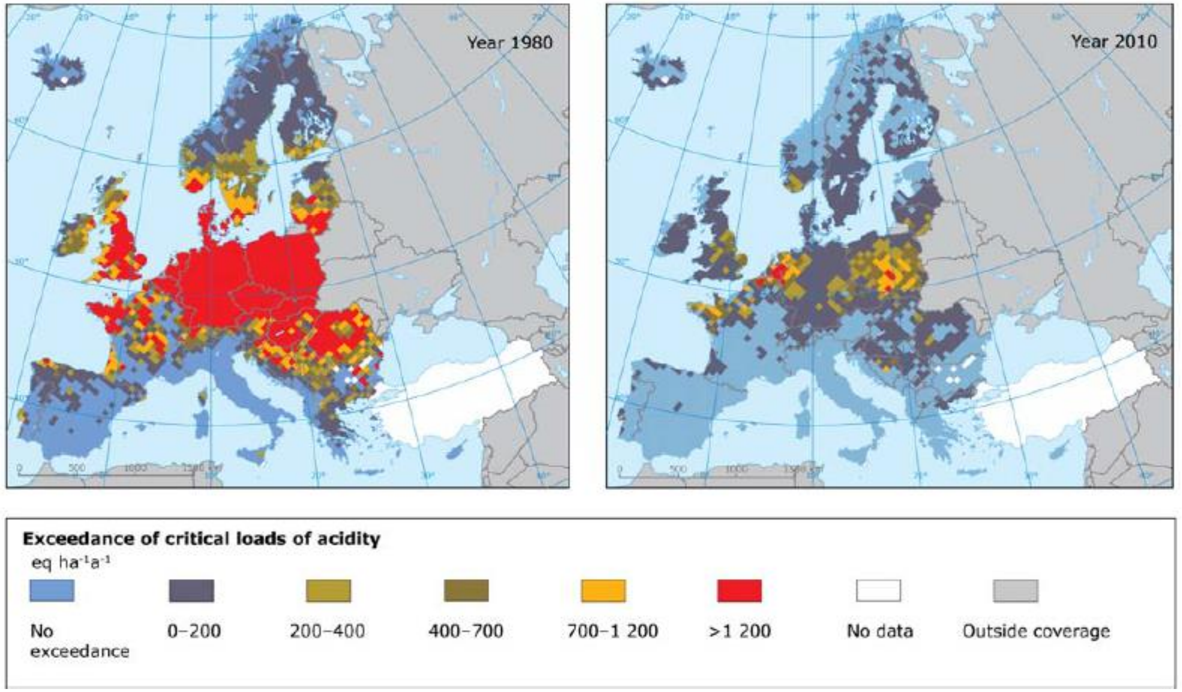


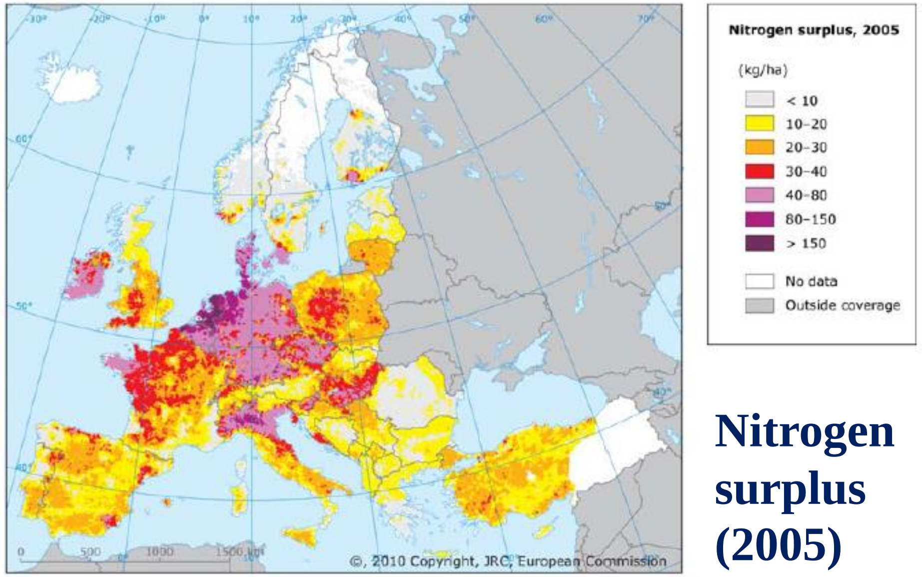
Figure 28: Predicted changes in soil organic carbon for croplands 1990–2080. The image on the left shows changes due to climate change only, while the map on the right shows changes as a result of variations in net primary production and the advent of new technologies related to crop management (e.g. machinery, pesticides, herbicides, agronomic knowledge of farmers) and breeding (e.g. improved stress resistance) that result in yield increases. The changes for other land cover types (grasslands, forests, heaths) will be different to those shown above.

Source: Smith et al., 2005.

Contamination

Industrialisation, waste management, agriculture. The most frequent contaminants are heavy metals and mineral oil.





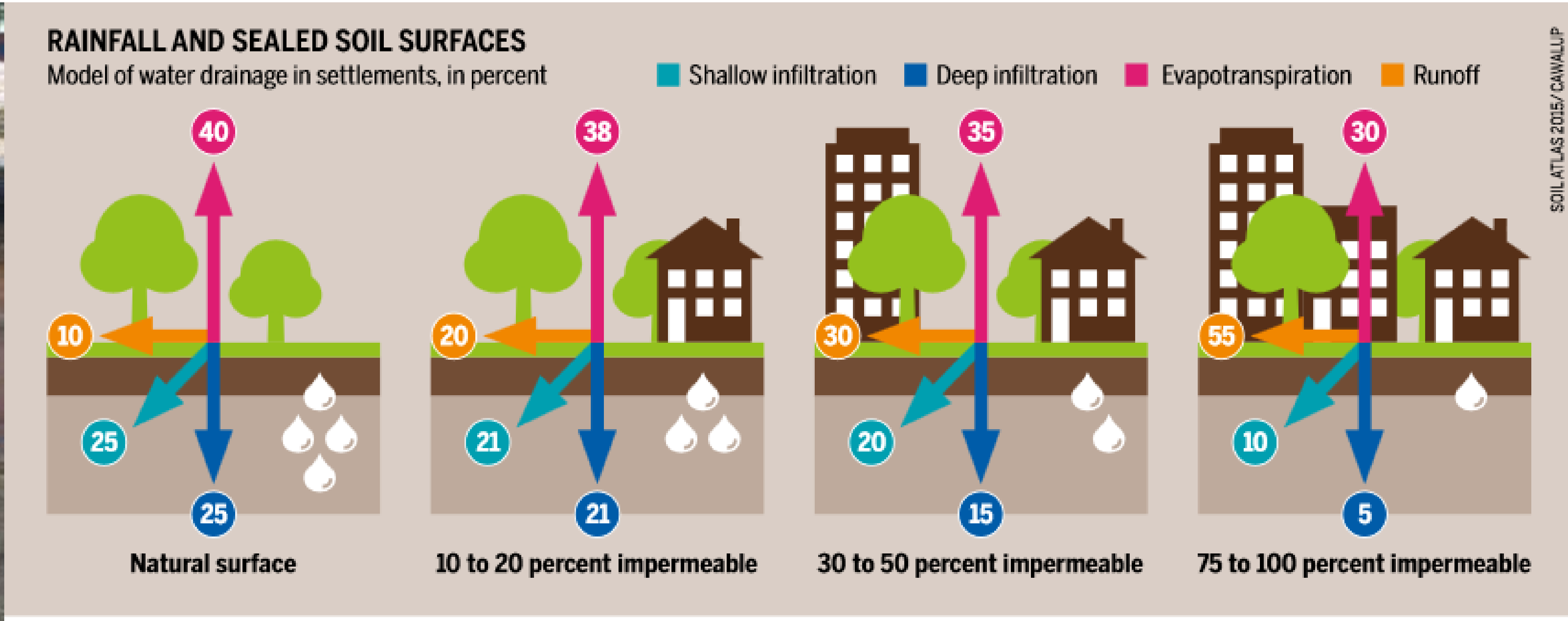
Nitrogen surplus (2005)

Sealing

Sealing occurs when agricultural or non-developed land is lost to urban sprawl, industrial development or transport infrastructure.

Between 1990 and 2000, at least 275 hectares of soil were lost per day in the EU, amounting to 1,000 km² / year.

Between 2000 and 2006, the EU average loss increased by 3%. (EC, 2011 - http://ec.europa.eu/environment/soil/sealing.htm)



30% of Veneto Municipalities has been hit by floods or landslides

Saove (Verona) 2010

Soil and human pressure

Agricutural practices

- Intensive agriculture
- Monoculture
- Lack, or reduced fallow

Demographic pressure

- Populationo dynamic
- Food habits (e.g., meat consumtion)

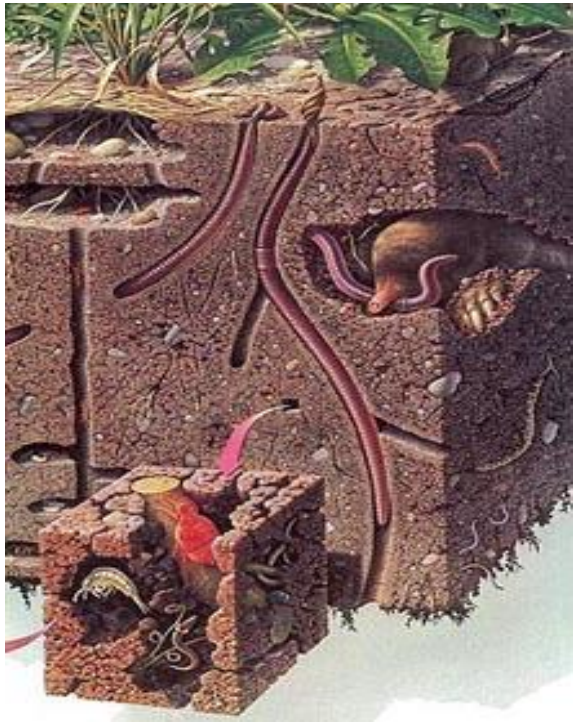
Biofuels

- Intensive farming
- Monoculture

Soil is affected by many pressures

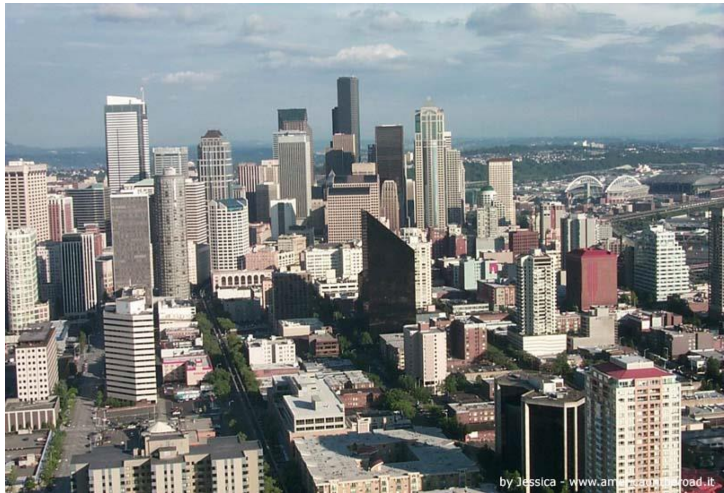
Productivity-food system

Population

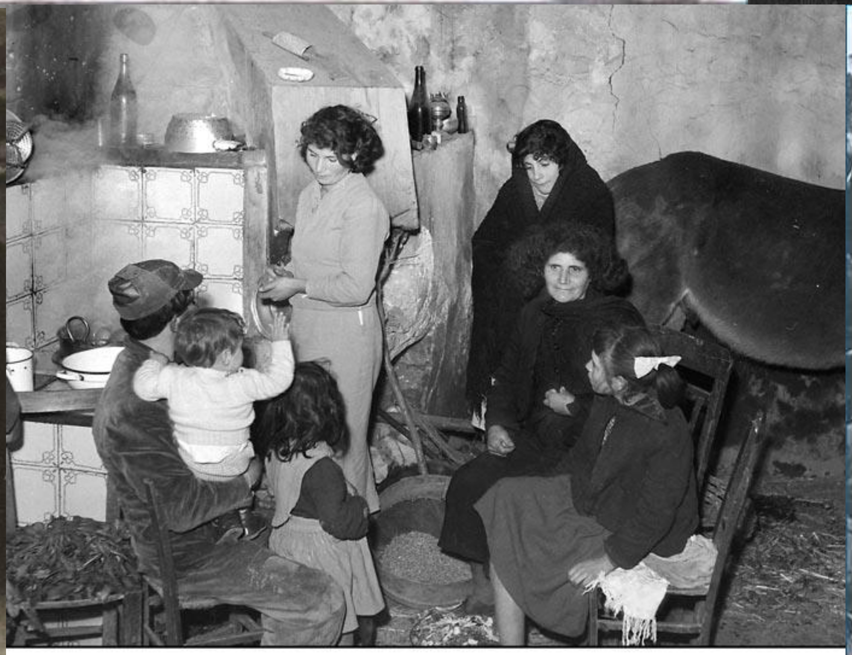


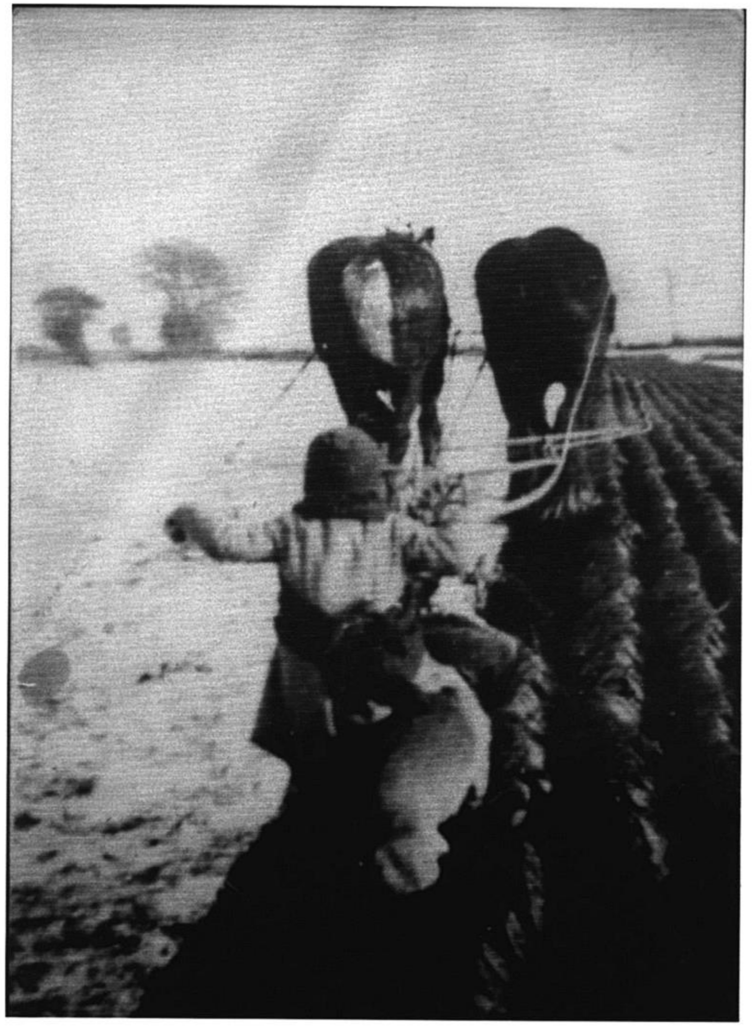
Climate

Urbanization



Life of Italian peasants until the 1950s-1960s:
Let’s say thanks to fossil fuels and the advance of agriculture






OIL
OIL
OIL

TABLE 6.4

Output/Input Analysis of New Guinea Swidden Agriculture for 1 ha of Mixed Crops That Included Sweet Potato, Taro, Cassava, Yam, and Banana

	h/ha	kcal/h	kcal/ha
Inputs			
Clearing underbrush	175	400	70,000
Clearing trees	68	400	27,200
Fencing garden	84	500	42,000
Weeding and burning	78	300	23,400
Placing soil retainers	44	400	17,600
Planting and all weeding	742	300	222,600
Other maintenance	137	400	54,800
Harvesting	277	300	83,100
Cartage	264	400	145,600
Subtotal	1869		686,300
Axe, machete (0.8 kg)[a]			16,860
Seeds, etc. (10 kg)[a]			36,000
Total			739,160
Outputs			
Crop yield			11,384,462
Output/input ratio			15.4:1

[a] Estimated as additional inputs.

Source: After Rappaport, R.A., *Pigs f* … *New Guinea People*, Yale University Press, New H … 6–132, 1971.

Decreasing marginal retun of energy invested in agriculture
(data from Pimentel and Hall, 1989)

Maize	Energy input (10^3 kcal ha^{-1})	Energy output (10^3 kcal ha^{-1})	Output/Input
Mexico Trad.	0.7	7	10:1
USA intensive	11	24	2:1
USA/Mexico	16	3.4	1/5

output/input
10:1

output/input
2:1

Which is best?

TABLE 7.1

Comparison of Energy Inputs for Tilling 1 ha of Soil by Human Power, Oxen, 6-HP Tractor, and 50-HP Tractor

Tilling Unit	Required Hours	Machinery Input (kcal)	Petroleum Input (kcal)	Human Power Input (kcal)	Oxen Power Input (kcal)	Total Input (kcal)
Human power	400	6000	0	194,000	—	200,000
Oxen (pair)	65	6000	0	31,525	260,000[a]	297,525
6-HP tractor	25	191,631	237,562[b]	12,125	—	441,318
50-HP tractor	4	245,288	306,303[c]	1940	—	553,531

Exosomatic energy

[a] Each ox is assumed to consume 20,000 kcal of feed per day.

[b] An estimated 23.5 L of gasoline used.

[c] An estimated 30.3 L of gasoline used.

Source: Pimentel, D. and Pimentel, M., *Food, Energy and Society*, Edward Arnold, London, 1979.

Indicators of performance of different farming systems

(data from Giampietro & Pimentel, 1994, p. 66)

Performances	Intensive USA (1985)	Trad. Mexico (only human labour)	China (1980)
kg/ha	7,400	1,944	2,700
kg/hr work	740	1.7	3.8
kcal input/kg maize	1,392	27	825
output/input	2.9	12.5	3.6

USA/Mex. 435

Which is best?

Can we find a way bettwen starving and get poisoned?

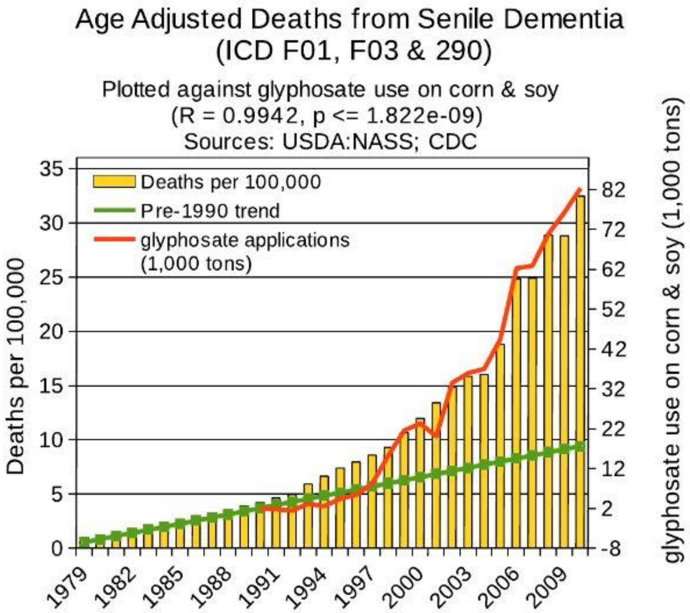


Figure 24. Correlation between age-adjusted dementia deaths and glyphosate applications.

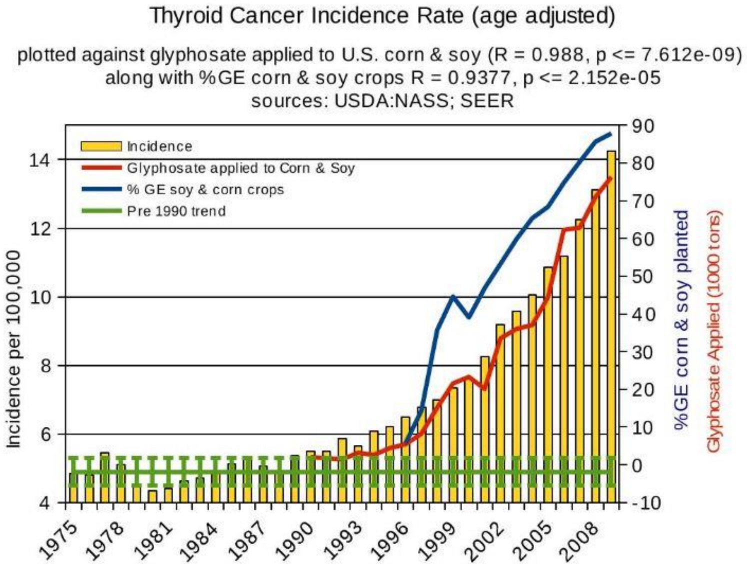


Figure 10. Correlation between age-adjusted thyroid cancer incidence and glyphosate applications and percentage of US corn and soy crops that are GE.

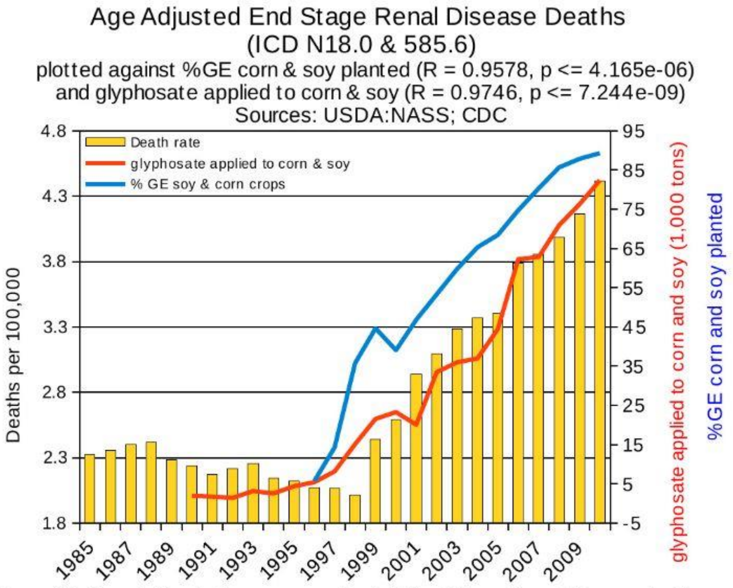


Figure 18. Correlation between age-adjusted End Stage Renal Disease deaths and glyphosate applications and percentage of US corn and soy crops that are GE.

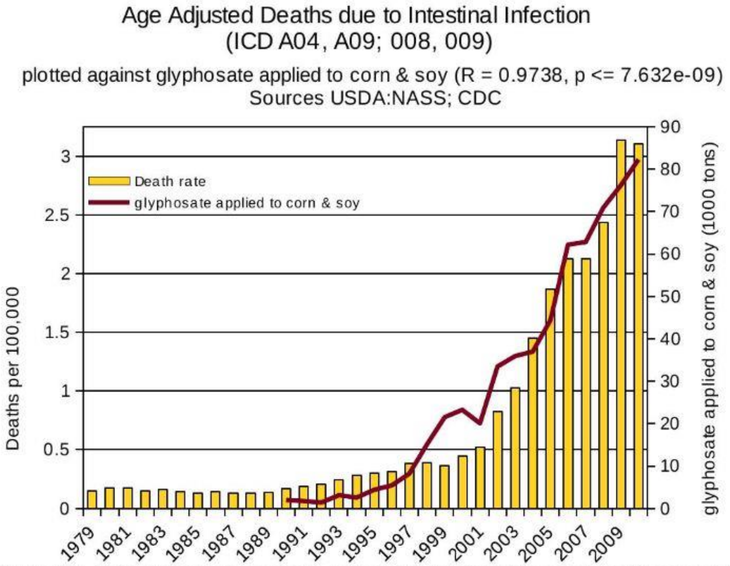
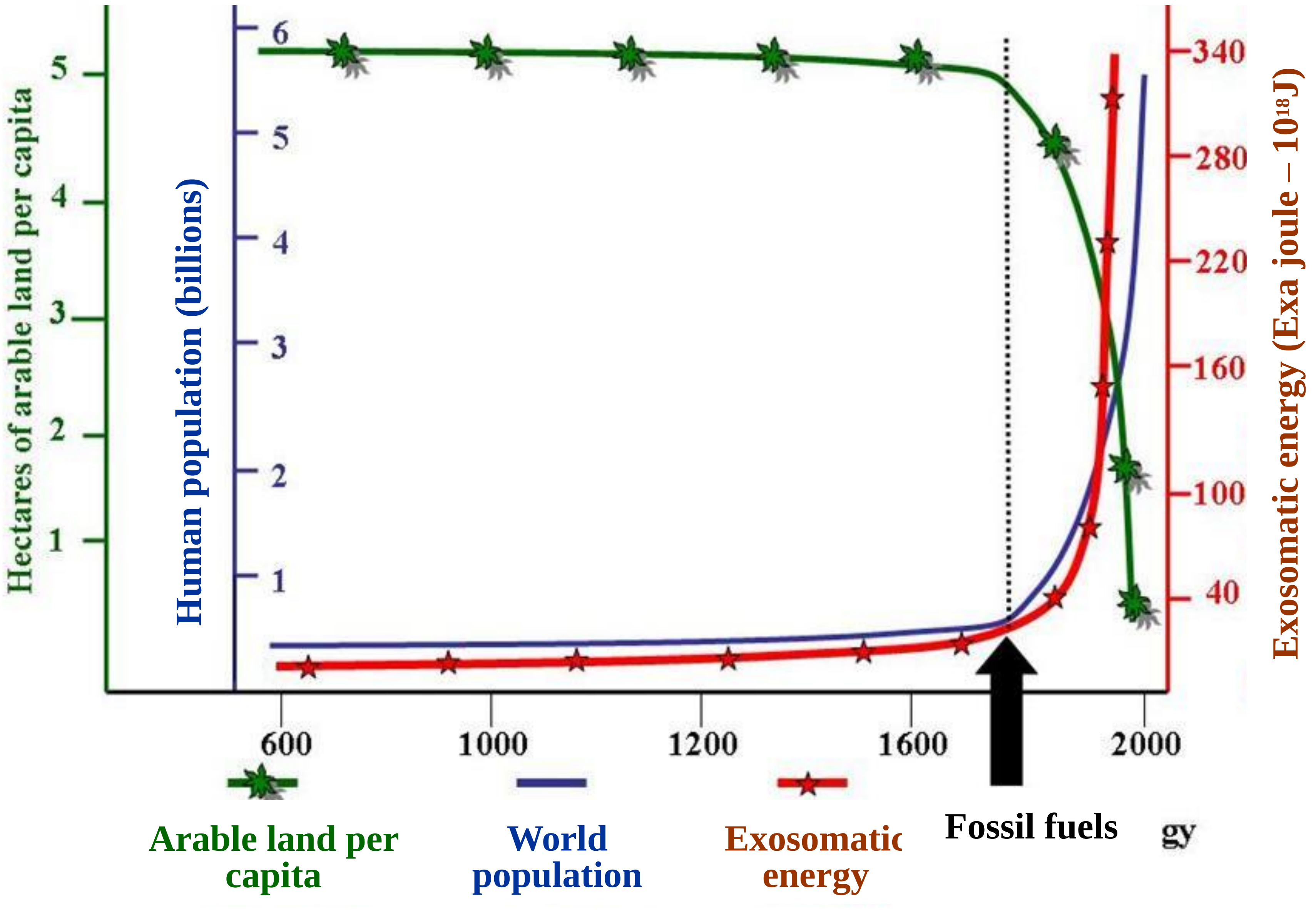


Figure 21. Correlation between age-adjusted intestinal infection deaths and glyphosate applications to US corn and soy crops.

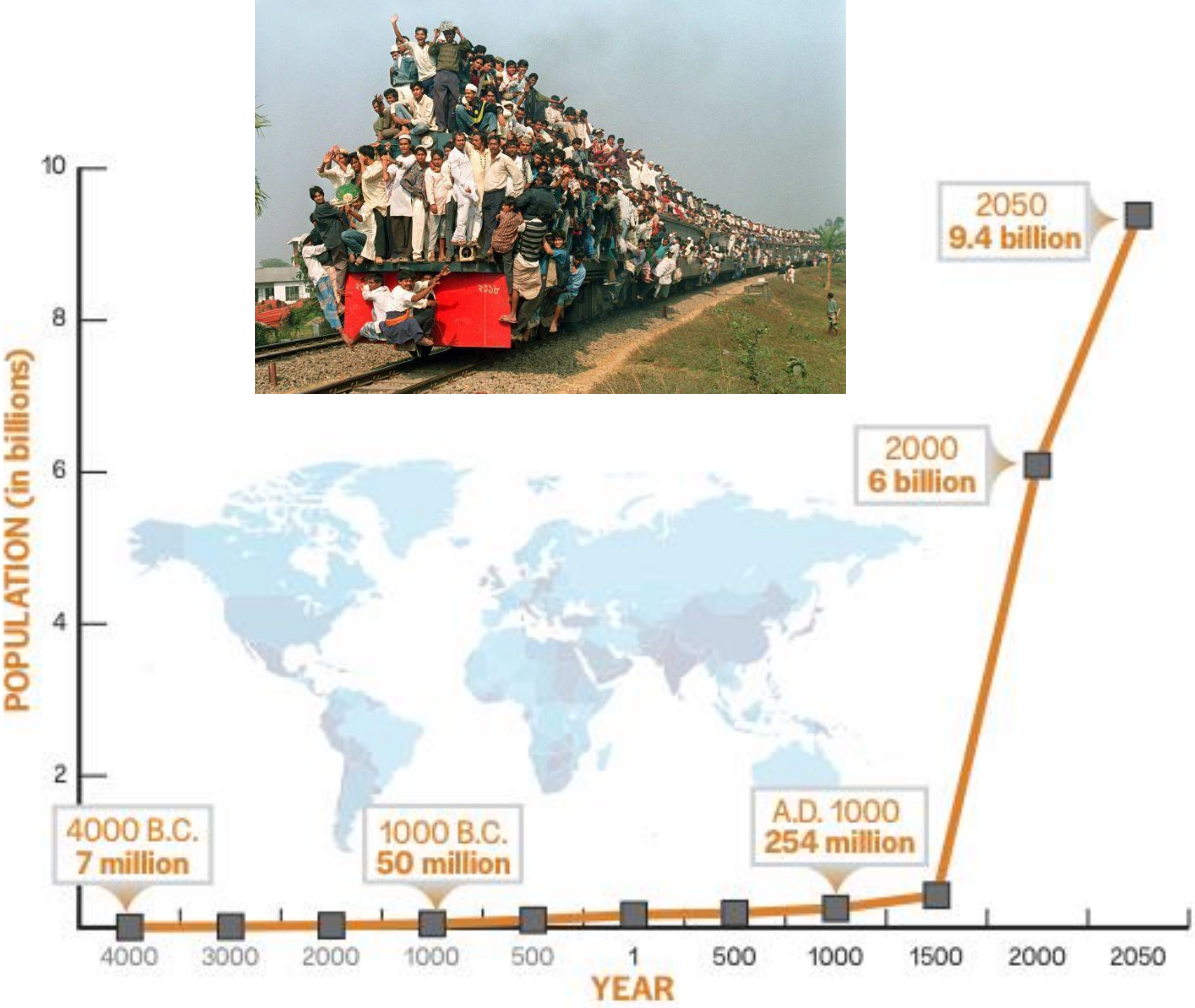
Swanson et al. 2014. Genetically engineered crops, glyphosate and the deterioration of health in the United States of America. Journal of Organic Systems, 9(2)

Fossil fuels population and land
(after Giampietro, 2007)



Demographic pressure

- Space
- Food (crops & livestock)
- Fibers
- Fuels
- Commodities
- Financial values (e.g., cost of land)



The negligible value of agriculture and the productivism paradigm

Is the current economic ideology threatening our future?

Daily, H.E., 2000. When smart people make dumb mistakes. *Ecological Economics*, 34: 1-3.

Nordhaus from Yale, Schelling from Harvard and Beckerman from Oxford dismiss the importance of climate change on the following line of reasoning,

(a) climate change will mainly affect agricultural activities;

(b) as agriculture represents a mere 3% of the USA GNP, even if 50% is lost that would just mean a mere 1.5% of the USA's GNP;

(c) such a figure may easily be compensated by the growth of the GNP in another sector of the economy.

"*True, agriculture accounts for only 3% of GNP, but it is precisely the specific 3% on which the other 97% is based! … "Yet some economists confuse fungibility of money with fungibility of real wealth, and proclaim publicly that they don't care if we produce computer chips or potato chips, as long as the dollar value is the same.*"

The big questions of the century…

Can we feed the incoming 2 billions people and properly feed the 1 billion still hungry?

FAO (2002), the arable area in developing countries will have to increase by almost 13%, or 120 million ha, over the years from 1997-99 to 2030 to meet the food demand (about double the area of France, 64 million ha).

Lambin et al., (2013) suggest that by 2030, an additional 81 to 147 million ha of cropland will be needed compared to the 2000 baseline.

BUT due to rapid urbanization, bioenergy policy mandates, forest plantations, and new protected areas, which are competing for land access, the total additional land demand is likely to range from 285 to 792 million ha between 2000 and 2030 (the contiguous surface of the USA – 800 million ha – without Alaska or other non-contiguous, overseas, states/territories).

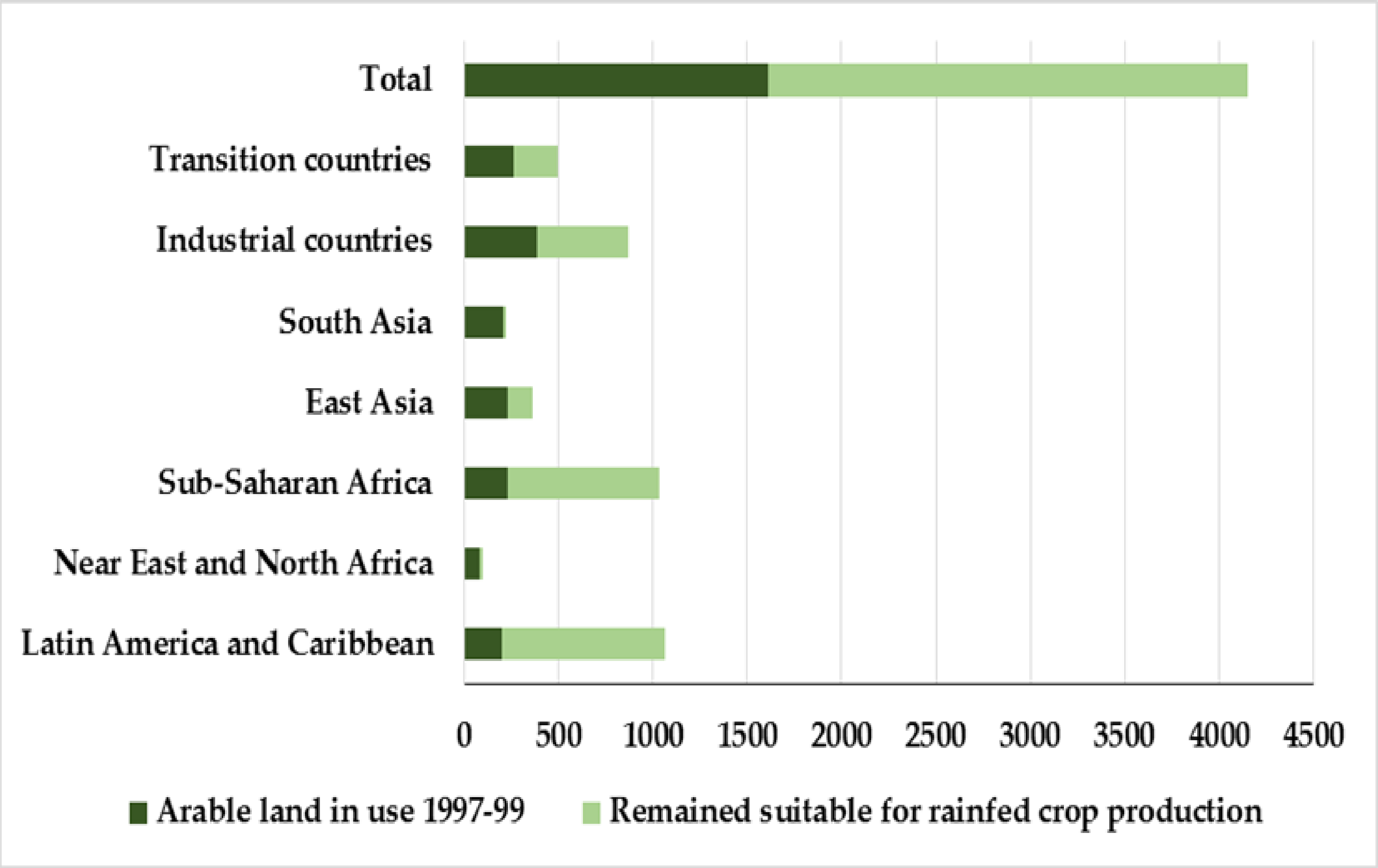
Is there enough land to meet future needs?

Optimistic view

The report by FAO (2002, p.41) stated that "*There is widespread concern that the world may be running out of agricultural land. … Despite these losses,* ***there is little evidence to suggest that global land scarcities lie ahead****. Between the early 1960s and the late 1990s, world cropland grew by only 11 percent, while world population almost doubled. As a result, cropland per person fell by 40 percent, from 0.43 ha to only 0.26 ha. Yet, over this same period, nutrition levels improved considerably and the real price of food declined. The explanation for this paradox is* ***that productivity growth reduced the amount of land needed to produce a given amount of food*** *by around 56 percent over this same period. This reduction, made possible by increases in yields and cropping intensities, more than matched the decline in area per person, allowing food production to increase*".

Alexandratos and Bruinsma (2012, p.10) state that "*there are sufficient spare food production resources in certain parts of the world, waiting to be employed* ***<u>if only economic and institutional frameworks would so dictate</u>***".

Market will solve it all?!



Distribution among regions of the present land in use and the potential suitable land that can be put in use (million ha). From Gomiero 2016, (data in Fisher et al., 2011, as reported in Alexandratos and Bruinsma, 2012).

The pessimists: Soil quality and soil degradation greatly affect agriculture productivity

- 70% to 80% of the Earth's land area is unsuitable for agriculture; to poor soils, steep topography, or adverse climate
- About 50% of the remaining area is already being cropped, and a large proportion of the other half is presently under tropical forests, that beneficially take up CO2

(Ramankutty et al., 2002)

The greatest potential for croplands in the current climate exists…

… in tropical Africa (560 million ha) and northern South America (470 million ha)

... we have still plenty of agricultural land if we cut the tropical forests!

The vision of converting the Amazon and Zaire basins into Asian-type rice-lands stems from a misunderstanding of the different biophysical soil characteristics of the former in comparison with the latter (Young, 1998) .

Problems with the present models are:

- statistics about yields might be unreliable
  - in many developing countries there is not a real measure of the areas harvested, yield or production.
  - figures may then be affected by assumptions (or even conditioned by speculative forces) rather than respond to realistic measurements.

- that in many poor countries the amount of land under cultivation is more than reported in the official statistics submitted by those countries to FAO.

- land use is mapped at a scale that does not account for the real morphology, characteristic and use of the land (e.g. hilly and rocky outcrops), leading to gaps in basic data

- data from different models are difficult to compare as they rely on different assumption, boundaries and protocols

- most of the land that FAO includes as potential cropland is actually represented by rain forests, grazing land and marginal land that may be providing ecosystem services

data used by FAO may greatly overestimate the amount of "free land" and the potential productivity

FAO models do not consider the quality of soil!

Why? They omitted this indicator because of the difficulty to have reliable data.

- Experts tend to converge on the fact that about 25% of the global land area is degraded, large differences concerning the estimates of the **intensity and extent** of the soil degradation.

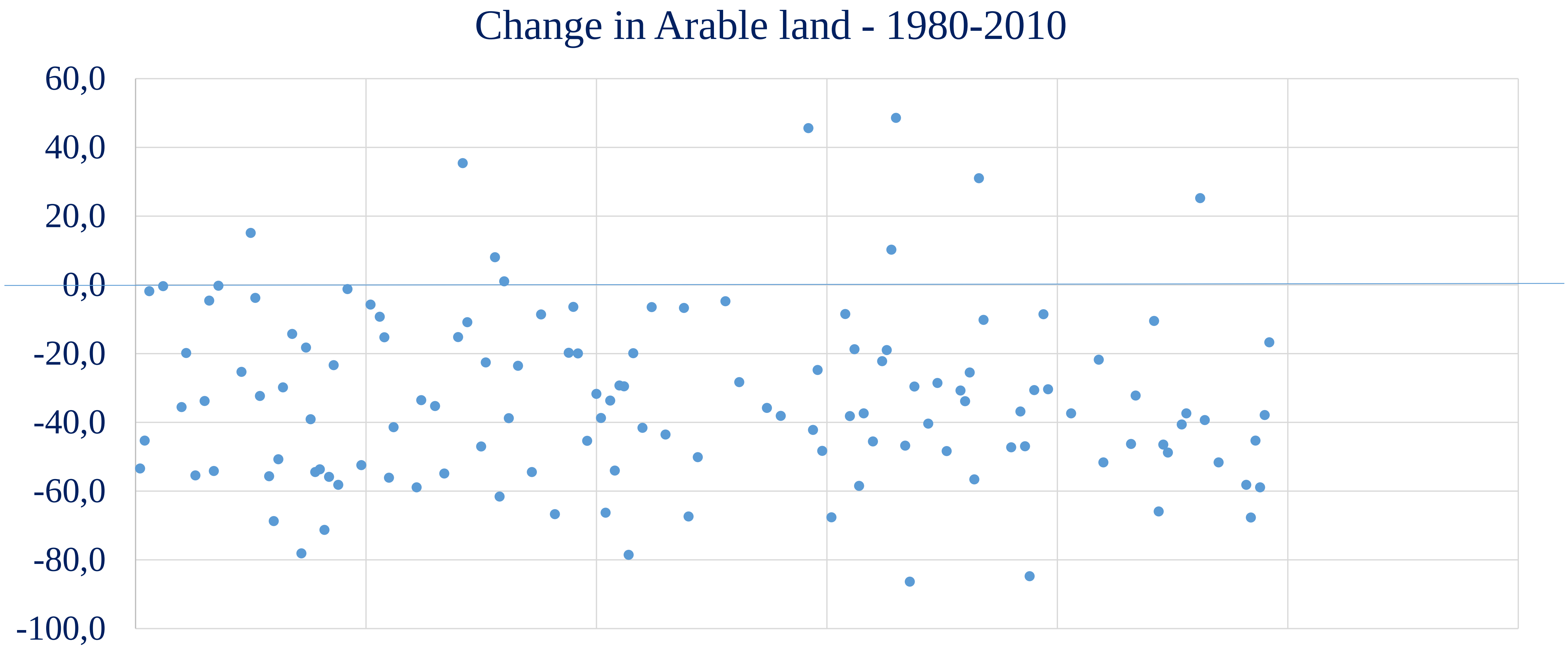
- **Soil degradation** affects land productivity directly, by reducing yield, and indirectly by increasing management costs (e.g. fertilizers, irrigation). For small and poor farmers that means indebtedness.

- In order to achieve high productivity of the new land, **irrigation is needed**

- **The key role of the future of energy supply is never addressed,** neither by the scenarios provided by FAO, nor by their critics. Our highly productive crops (and food system) need a lot of energy…

- The **effects of trade and globalization** bring a lot of uncertainty in how they will affect the agricultural sector in different regions/countries, we have also to consider credit, financial speculation, conflicts.

Loss of arable land



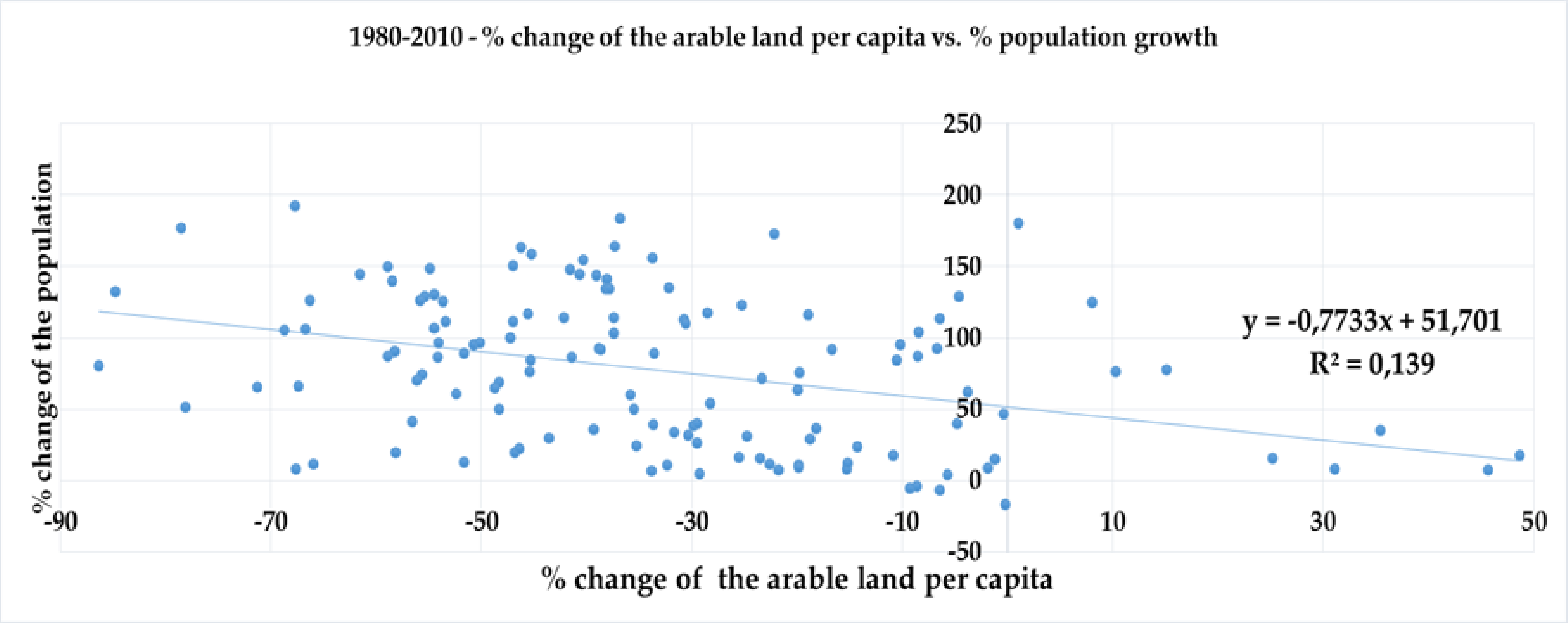
Change in arable land from 1980-2010 for a dataset of countries (data for arable land per capita and GDP per capita from the World Bank database – WB, 2015)

Why arable land is an important indicator

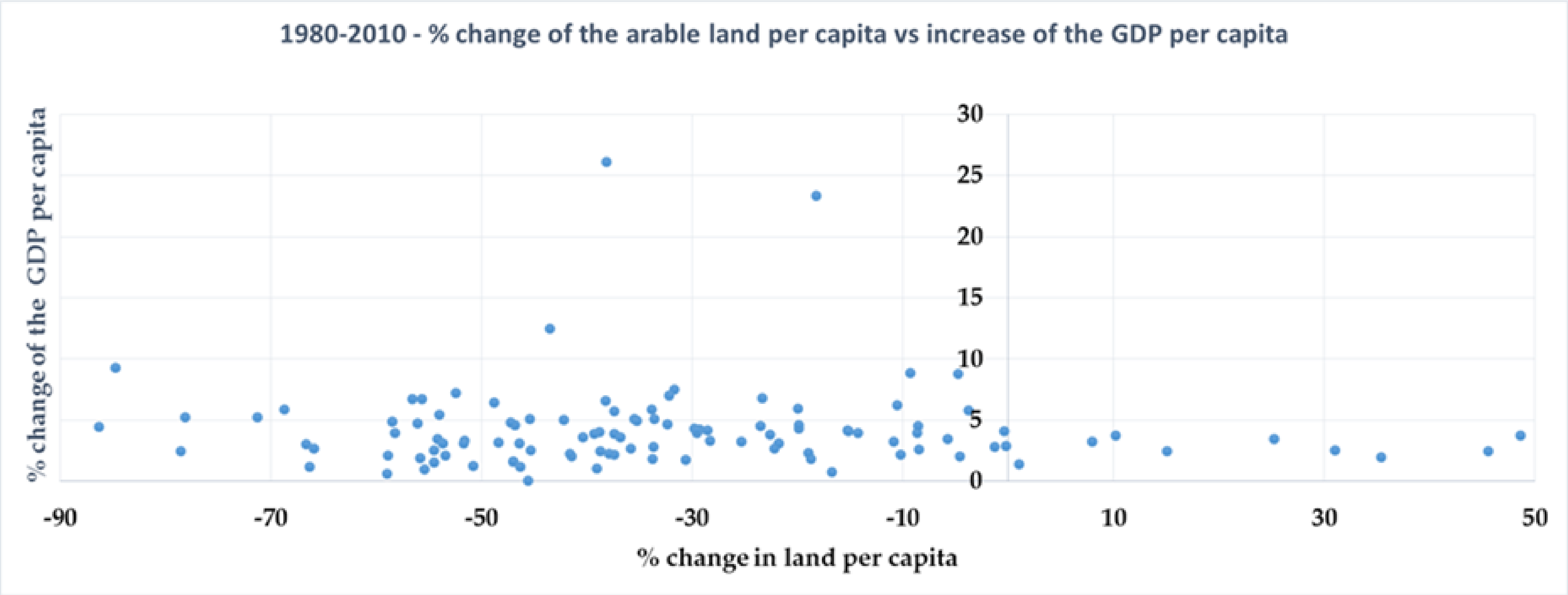
- Best quality, most productive soil
- Plain or very mild slope
- Next to the water table
- Reduced erosion
- Reducend working time (machinery easy to use)
- Reduced inputs
- Reduced costs



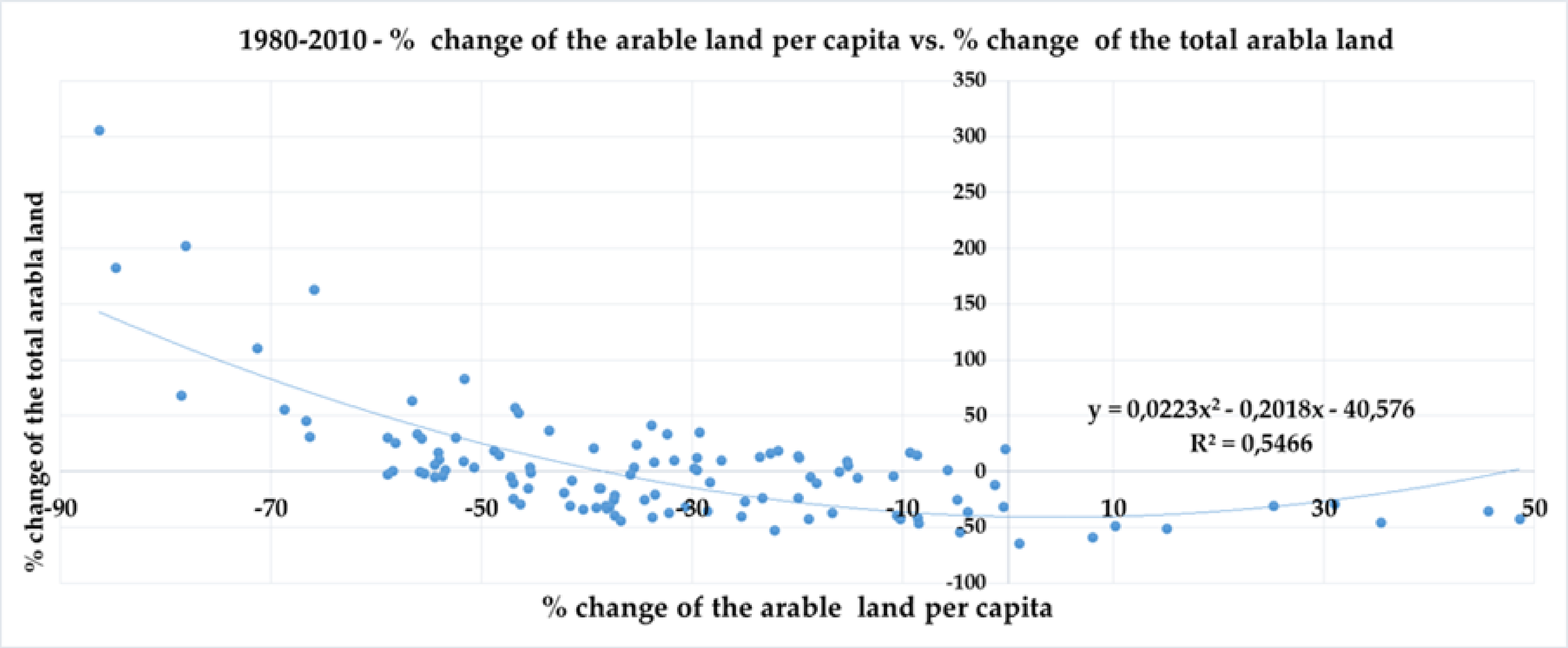

Moving away from these conditions reduce the return on the investment and increase soil degradation



Change in arable land vs. change in population, from 1980-2010 for a dataset of countries (data for arable land per capita and population from the World Bank database – WB, 2015)



Change in arable land vs. GDP growth, from 1980-2010 for a dataset of countries (data for arable land per capita and GDP per capita from the World Bank database – WB, 2015)



Change in arable land vs. change of the total arable land, from 1980-2010 for a dataset of countries (data for arable land per capita and population from the World Bank database – WB, 2015)

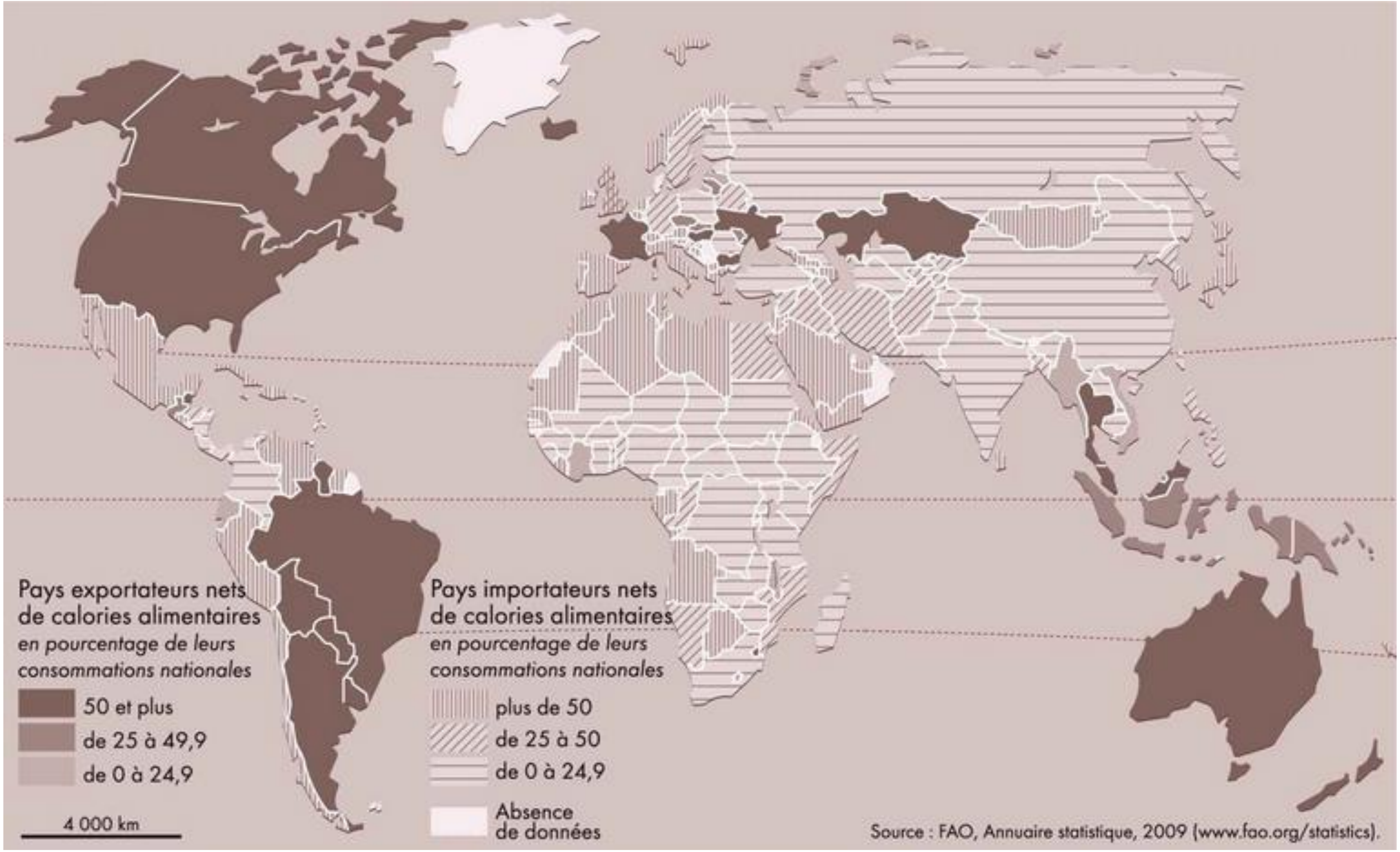
But... are we not producing more than enough?

Heterogeneity of contexts: Land, people and food are not distributed evenly

Trends for population and arable land per capita for the world's ten most populated countries (% arable land per capita calculated on WB data on arable land and population)

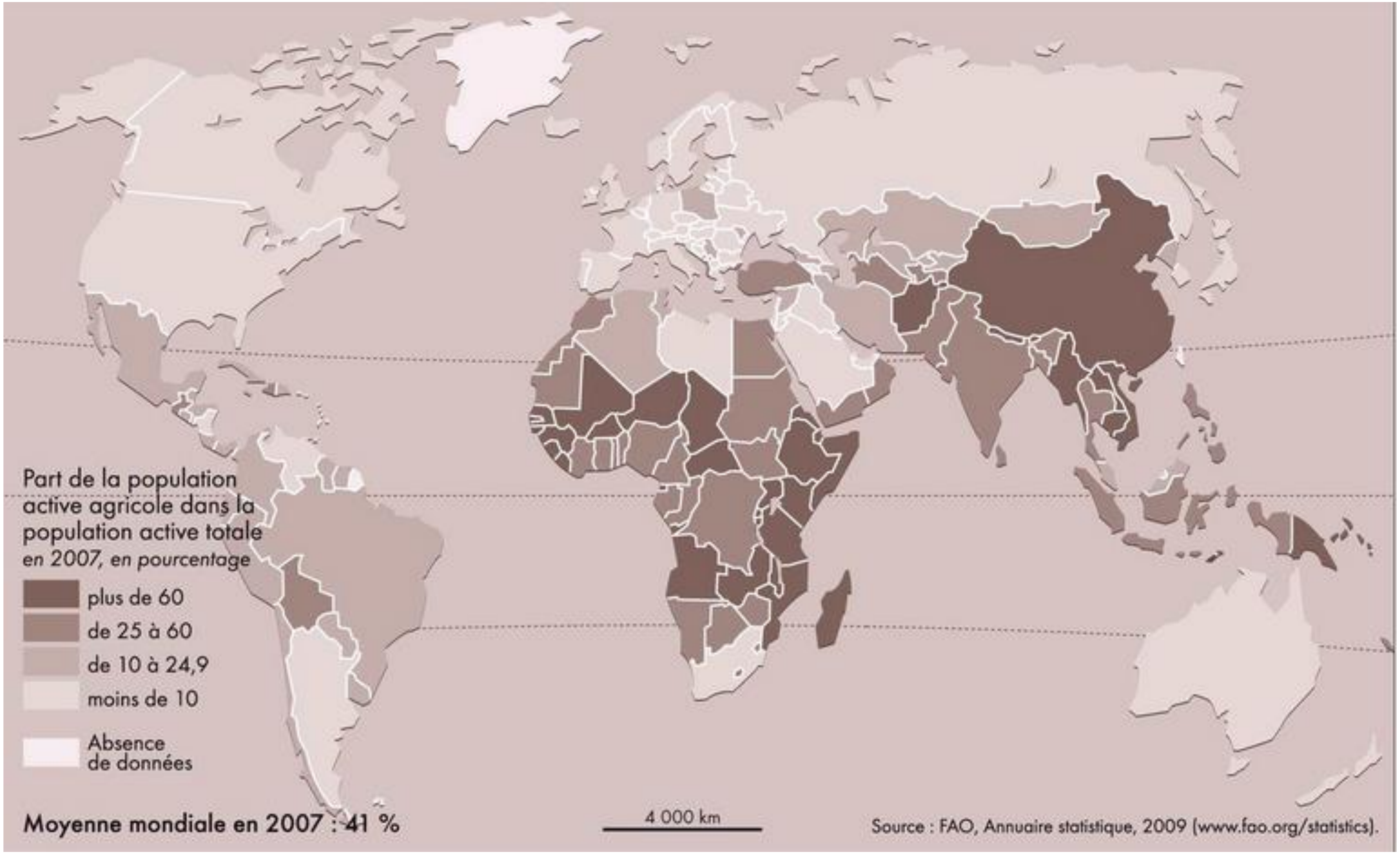
Top 10 most populated countries	Pop. year 2014[WB] (M)	% world pop. (7,260 M)	% arable land per capita 1980-2010	Arable land ha/capita (2013)	Pop. growth (annual %) (2011-2015)	Pop. 2030 (est.)[UN]	Pop. 2050 (est.) [UN]
China	1.364	18.8	-18	0.08	0.5	1.415	1.348
India	1.295	17.8	-45	0.12	1.2	1.527	1.705
USA	319	4.4	-39	0.48	0.7	356	389
Indonesia	254	3.5	-20	0.09	1.3	295	322
Brazil	206	2.8	-4	0.37	0.9	229	238
Pakistan	185	2.5	-28	0.17	2.1	244	309
Nigeria	177	2.4	-19	0.20	2.7	262	398
Bangladesh	159	2.2	-54	0.04	1.2	186	202
Russian Fed.	144	2.0	-8*	0.85	0.2	139	127
Japan	127	1.7	-20	0.03	-0.2	120	107

Exporters and importers of food (kcal)



Atlas de l'agriculture - Comment pourra-t-on nourrir le monde en 2050 ?, Jean-Paul Charvet, ed. Autrement, 2010

Active population working in agriculture (%)



Being hungry in the and of planty: The USA case

The USA has 0.5ha of arable land per capita, the second highest value in the world, after Russia.

Cochrane (1993) talks about a continuous problem of surplus for the US agriculture since the XVIII century. Hurt (2002), tells of a continuous "problem of plenty"; since the 1930s, the main agricultural issue that all the governments have been faced with is how to get rid of the surplus.

Burning the surplus, producing "green fuels", seems the final solution. Nearly half of USA maize production ends up generating ethanol (at a cost for the taxpayers as this is a very inefficient process).

Yet it seems that the main issue for US agriculture is to increase productivity!

Genetically modified crops account for nearly all the maize, soybean, cotton, canola, sugar beet, etc.

Yet the USDA reports that in 2012, 14.5% of households (about 45 million people) were food insecure, meaning they had difficulty at some time during the year obtaining enough food due to a lack of resources

Waste to livestock: Could reducing meat consumption help?

Livestock production accounts for 70% of all agricultural land and 30% of the land surface of the planet.

The expansion of livestock production plays a key role in deforestation, GHGs emission and water consumption. In the case of the Amazonas, 70% of previous forested land is now occupied by pastures, and feed crops cover a large part of the remainder.

When considering the entire commodity chain, **livestock production is estimated to release every year into the atmosphere 6,5 billions of CO2-equivalent GHGs, accounting for 18% of the global GHGs emissions, a larger share than that of transportation**.

To produce 1,000 $kcal^{-1}$ of food it requires about 0.5 m^3 for cereals and about 4 m^3 for meat.

In the U.S., livestocks are responsible for an estimated 55% of erosion and sediment, 37% of pesticide use, 50% of antibiotic use, and 30% of the high amount of nitrogen and phosphorus contaminating freshwater ecosystems

Cassedy et al. 2015

Given the current mix of crop uses, growing food exclusively for direct human consumption could increase available food calories by as much as 70%.

Such a staggering supply of energy could suffice to properly feed 4 billion people.

Even small shifts in our allocation of crops to animal feed and biofuels could significantly increase global food availability, helping to ensure global food security.

Could not a drastic reduction in meat and dairy consumption in developed countries, represent a simple solution to all these problems?

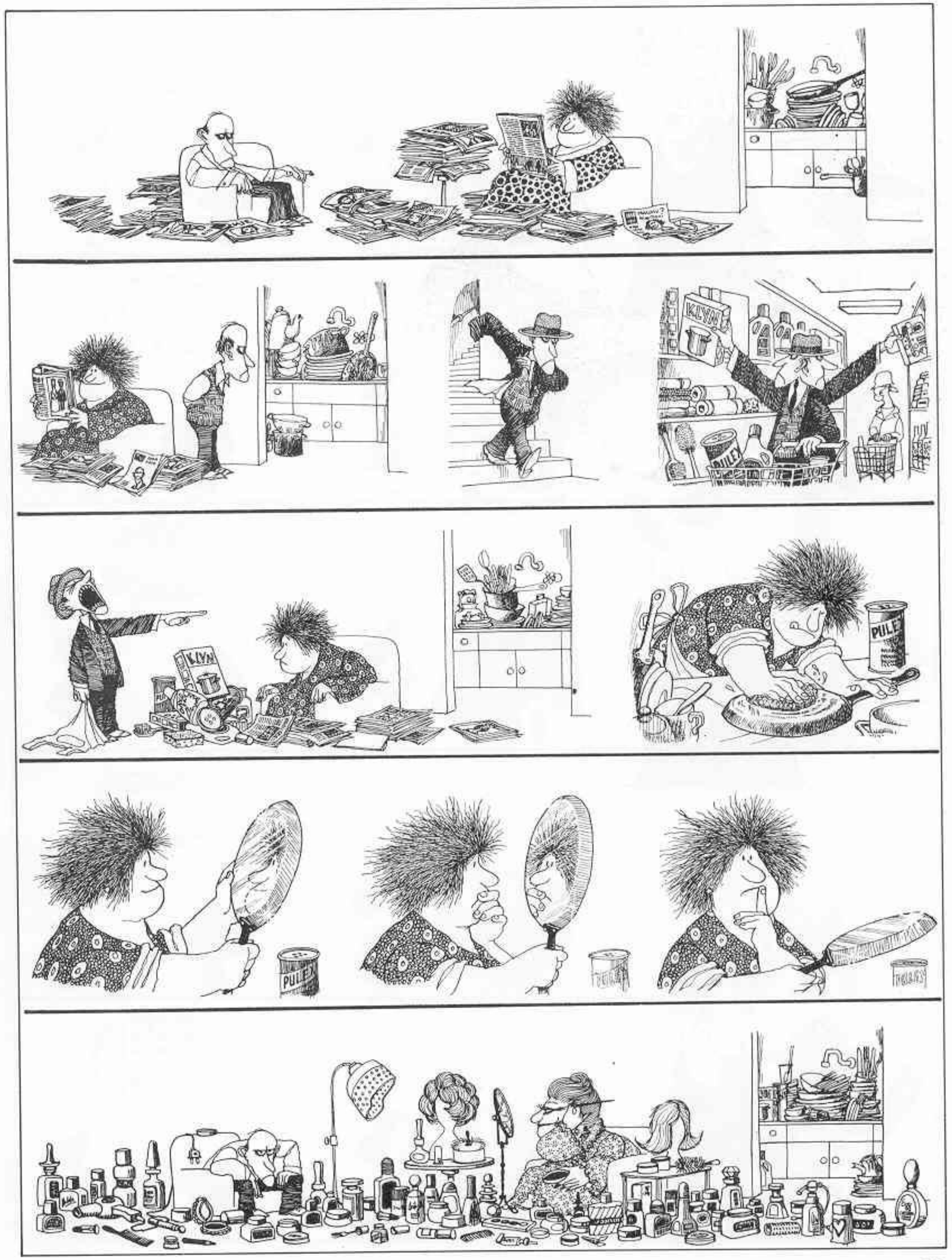
Complexity and rebounds

Rosegrant et at. (1999),

Decreasing meat and dairy consumption in developed countries may lead to an overall increase in meat and dairy consumption at a global level!

Rebound: *"The lower meat consumption in the developed countries and the resulting decline in world meat prices induce increased meat consumption in the developing countries."*

The fall of the demand for livestock in developed countries may make meat and dairy affordable to for consumers of developing countries, boosting the demand and, in turn, the production, as the meat industry would have to massively increase its supply due to the reduced economic return per unit produced.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