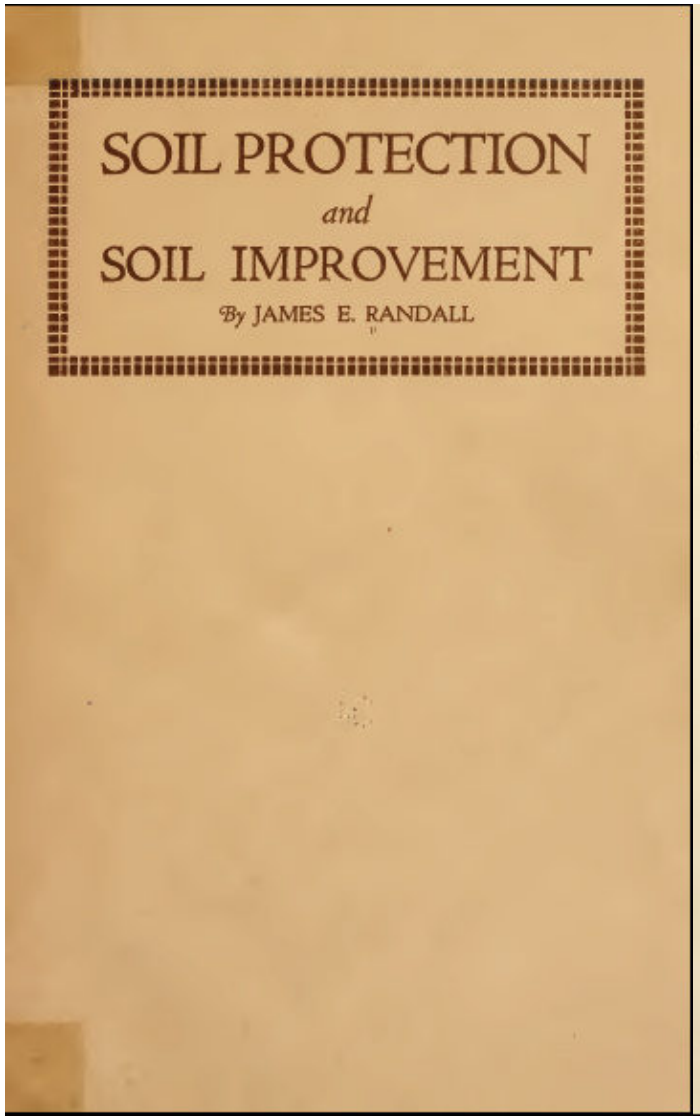
GLOBAL CHALLENGES FOR SUSTAINABLE LANDUSE AND SOIL PROTECTIONS

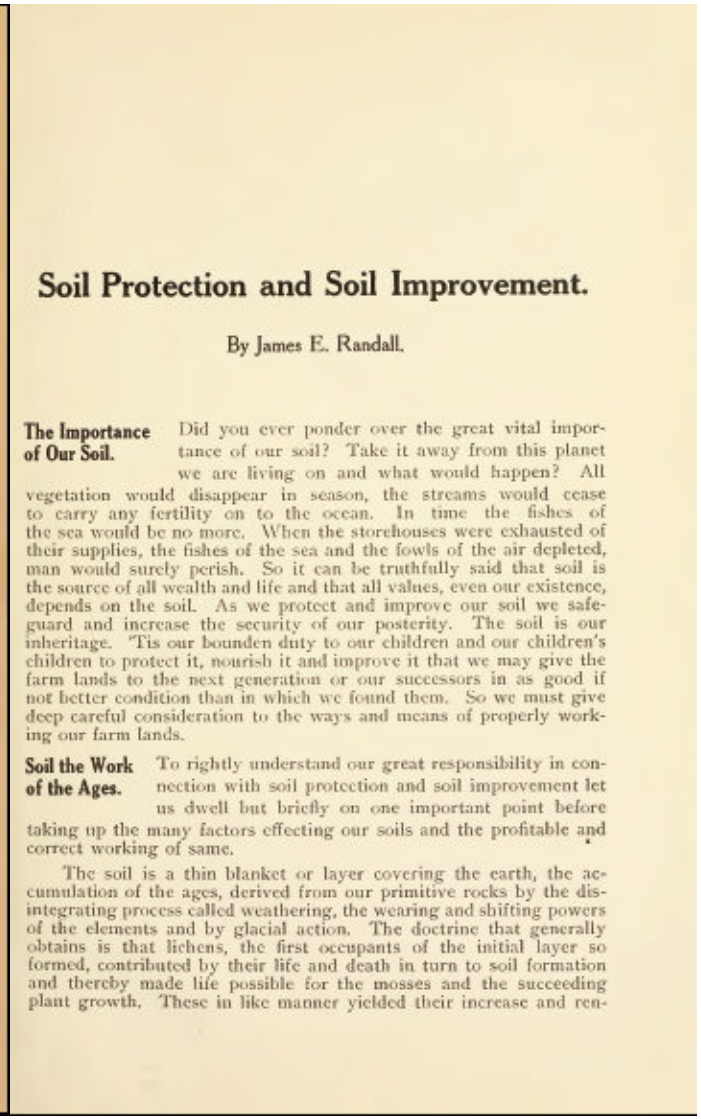
University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

… soil resources, their availability, use and management in an ever changing world

Walter W. Wenzel
Professor, Soil Protection & Soil Management
Institute of Soil Research

Soil Protection & Soil Management





Soil Protection and Soil Improvement.

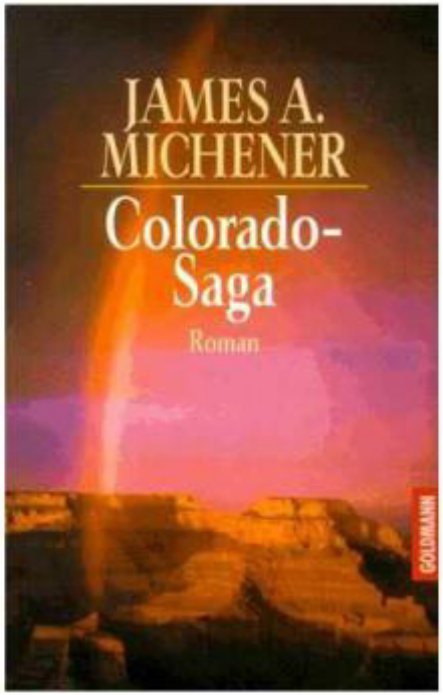
By James E. Randall.

The Importance of Our Soil. Did you ever ponder over the great vital importance of our soil? Take it away from this planet we are living on and what would happen? All vegetation would disappear in season, the streams would cease to carry any fertility on to the ocean. In time the fishes of the sea would be no more. When the storehouses were exhausted of their supplies, the fishes of the sea and the fowls of the air depleted, man would surely perish. So it can be truthfully said that soil is the source of all wealth and life and that all values, even our existence, depends on the soil. As we protect and improve our soil we safeguard and increase the security of our posterity. The soil is our inheritage. 'Tis our bounden duty to our children and our children's children to protect it, nourish it and improve it that we may give the farm lands to the next generation or our successors in as good if not better condition than in which we found them. So we must give deep careful consideration to the ways and means of properly working our farm lands.

Soil the Work of the Ages. To rightly understand our great responsibility in connection with soil protection and soil improvement let us dwell but briefly on one important point before taking up the many factors effecting our soils and the profitable and correct working of same.

The soil is a thin blanket or layer covering the earth, the accumulation of the ages, derived from our primitive rocks by the disintegrating process called weathering, the wearing and shifting powers of the elements and by glacial action. The doctrine that generally obtains is that lichens, the first occupants of the initial layer so formed, contributed by their life and death in turn to soil formation and thereby made life possible for the mosses and the succeeding plant growth. These in like manner yielded their increase and ren-

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences



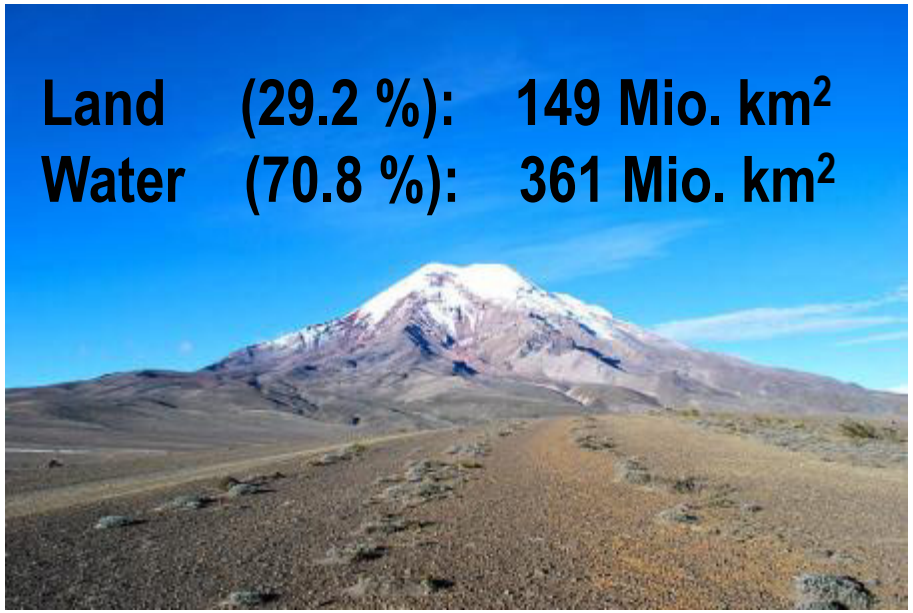
Land Use Changes

" The Blue Marble" photograph of Earth, taken from *Apollo 17*

http://en.wikipedia.org/wiki/Earth

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Earth´s surface: 510 Mio. km^2

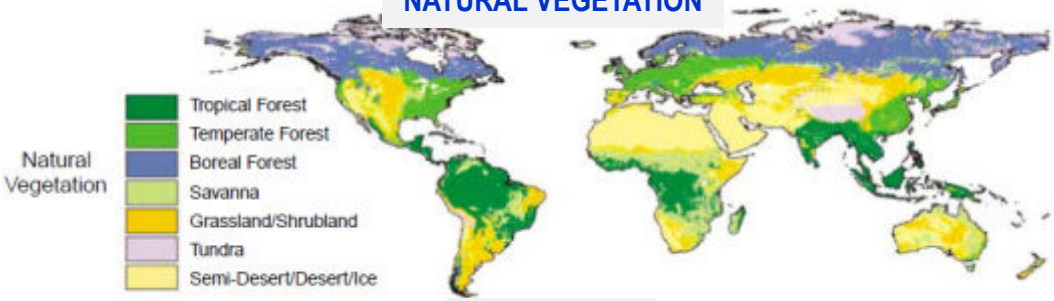


Land Use Changes

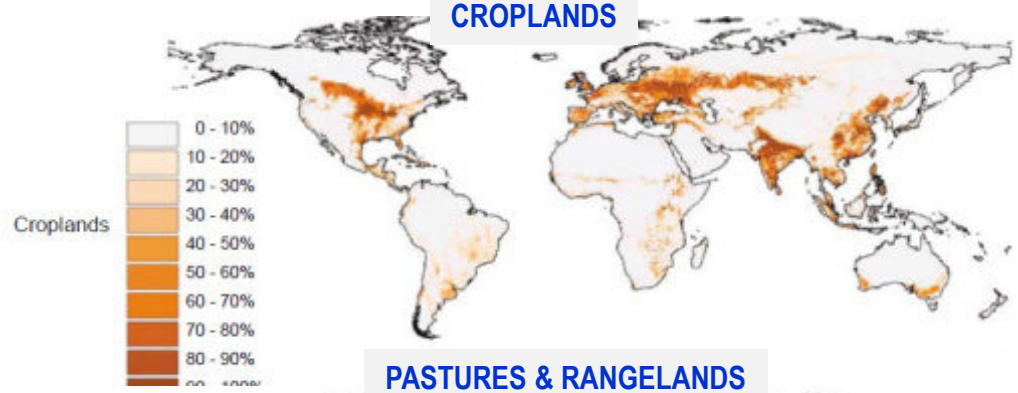
University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Global Changes

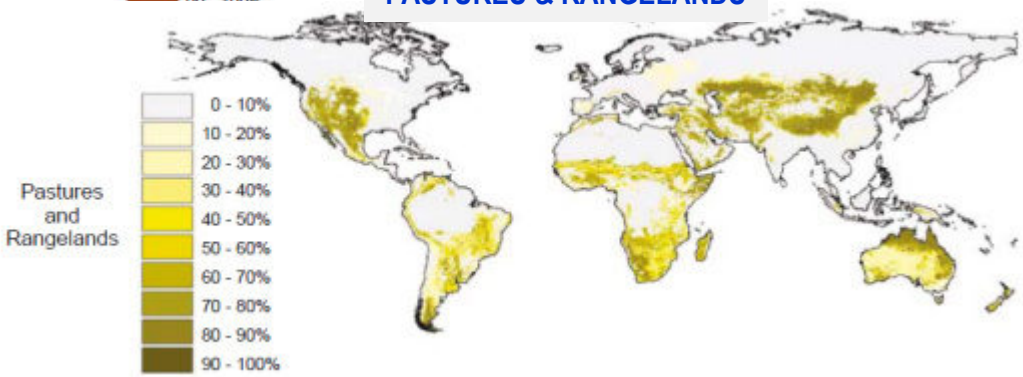
NATURAL VEGETATION



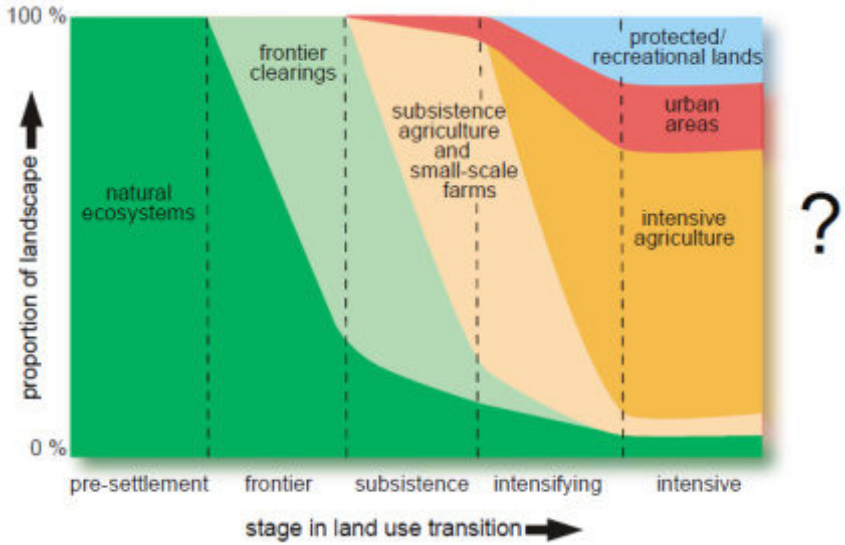
CROPLANDS



PASTURES & RANGELANDS



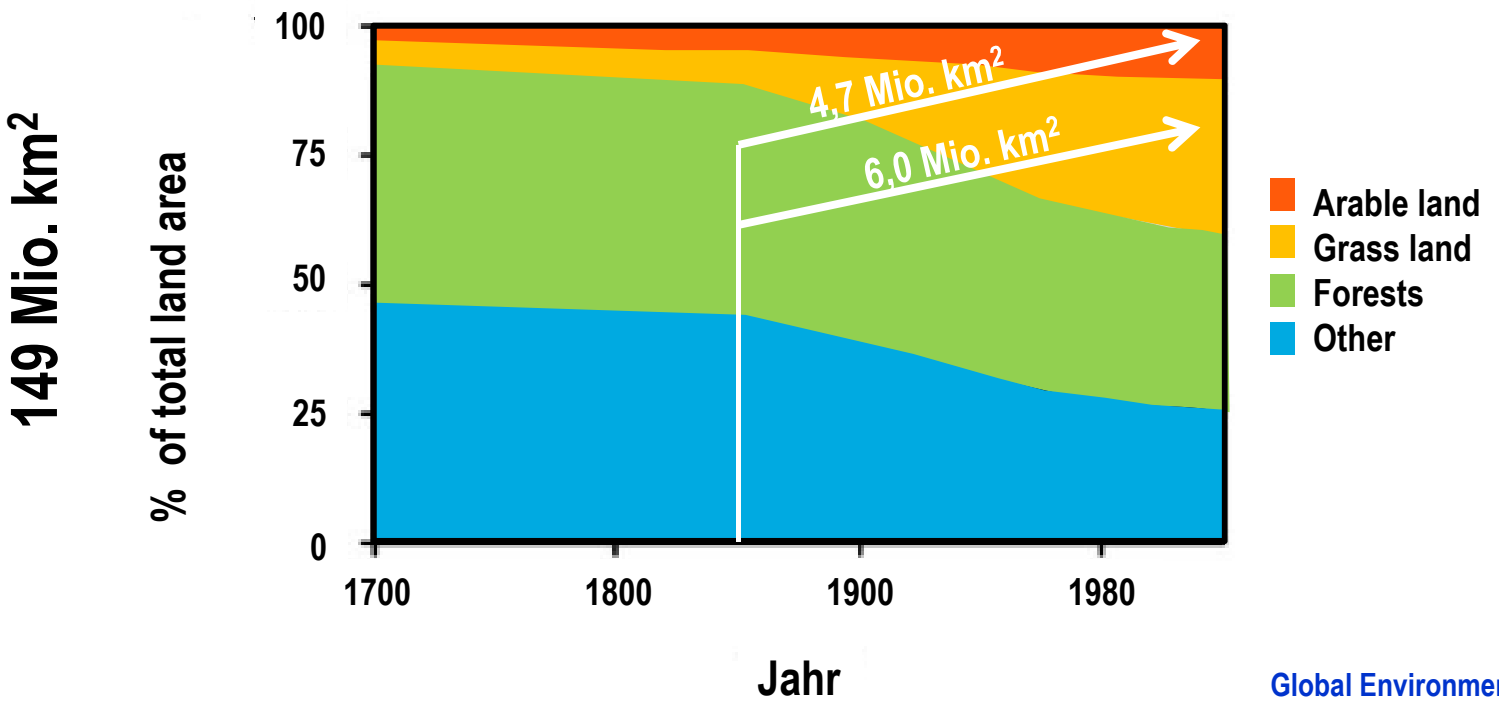
Foley et al (2005)
Science 309: 570-574



Land Use Changes

Global Changes

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

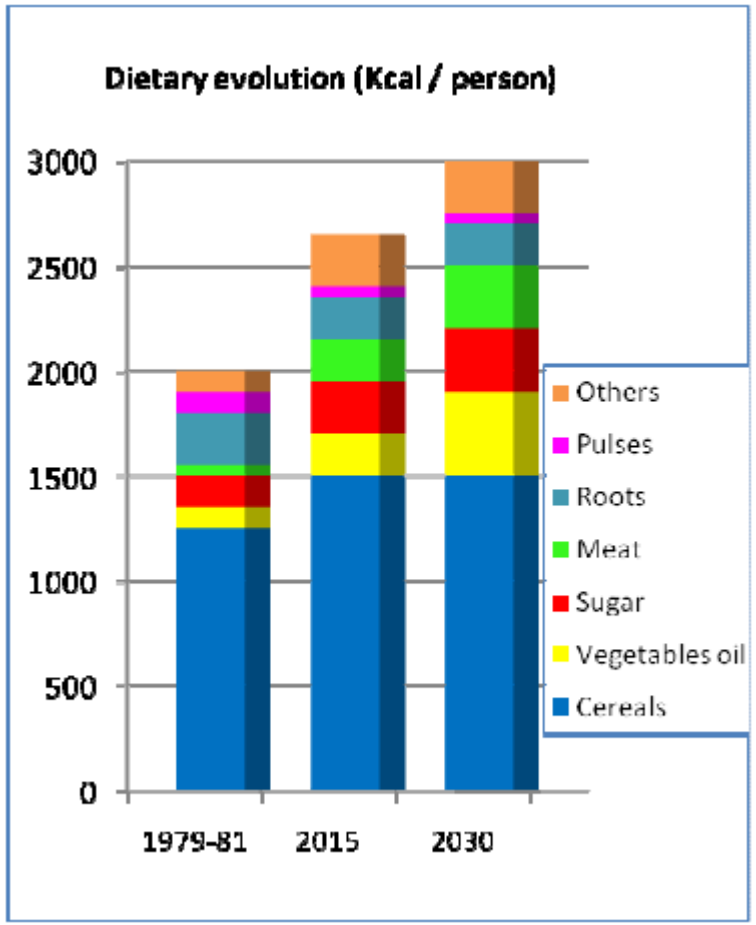


Lambin et al. (2001)
Global Environmental Change 11: 261-269

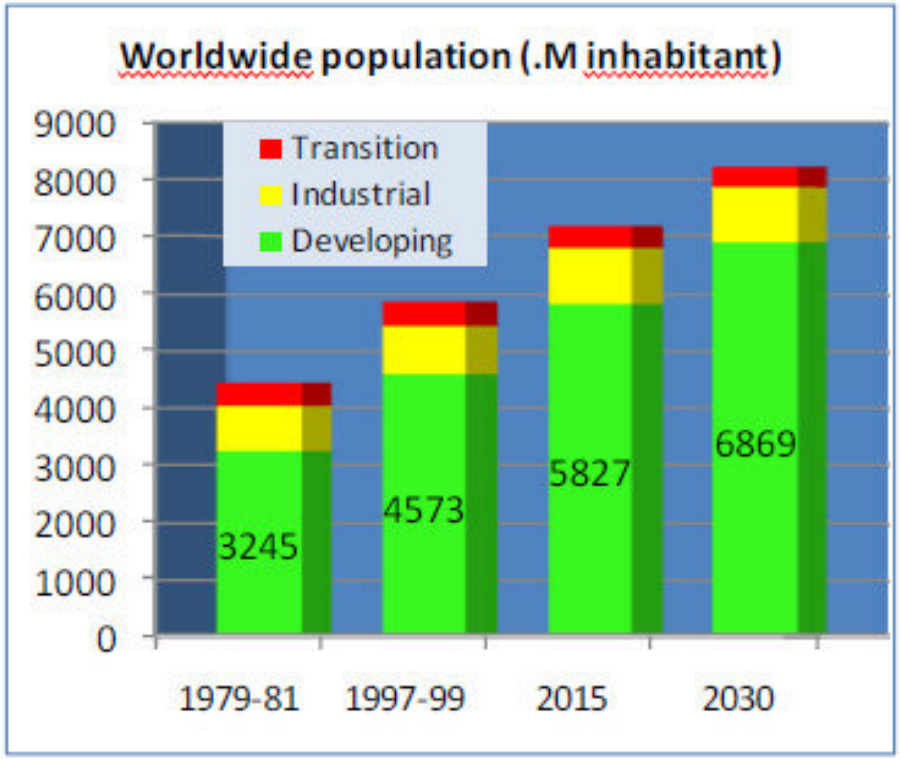
Increasing Land Demand

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Global changes will continue



Source: TIMAC AGRO



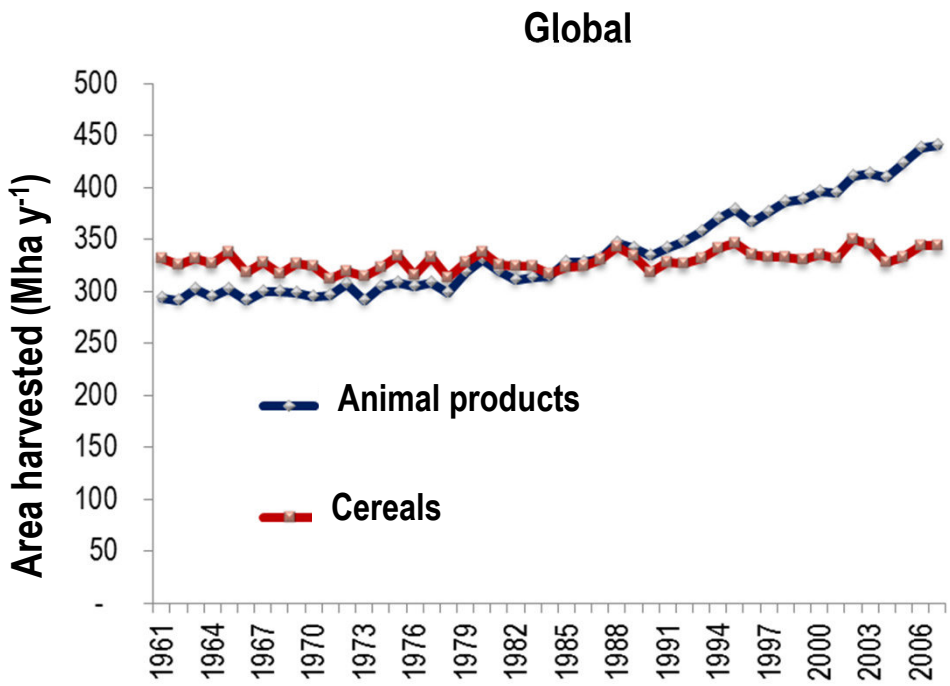
Increasing Land Demand

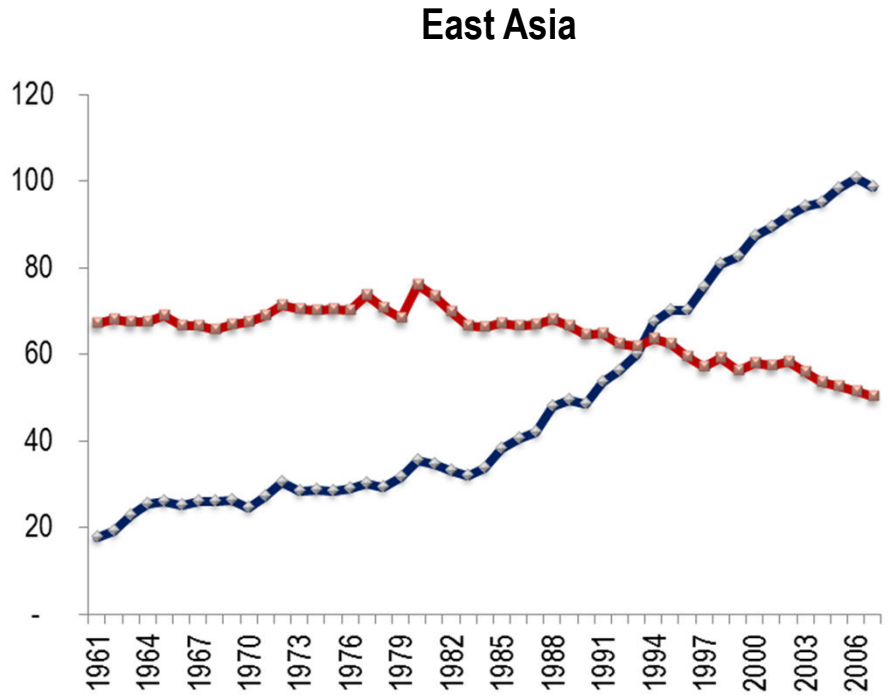
University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Total land area required for food production

- Nutritional habits (meat consumption)
- Population growth

Datenquelle: Kastner et al. (2012)
PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1117054109



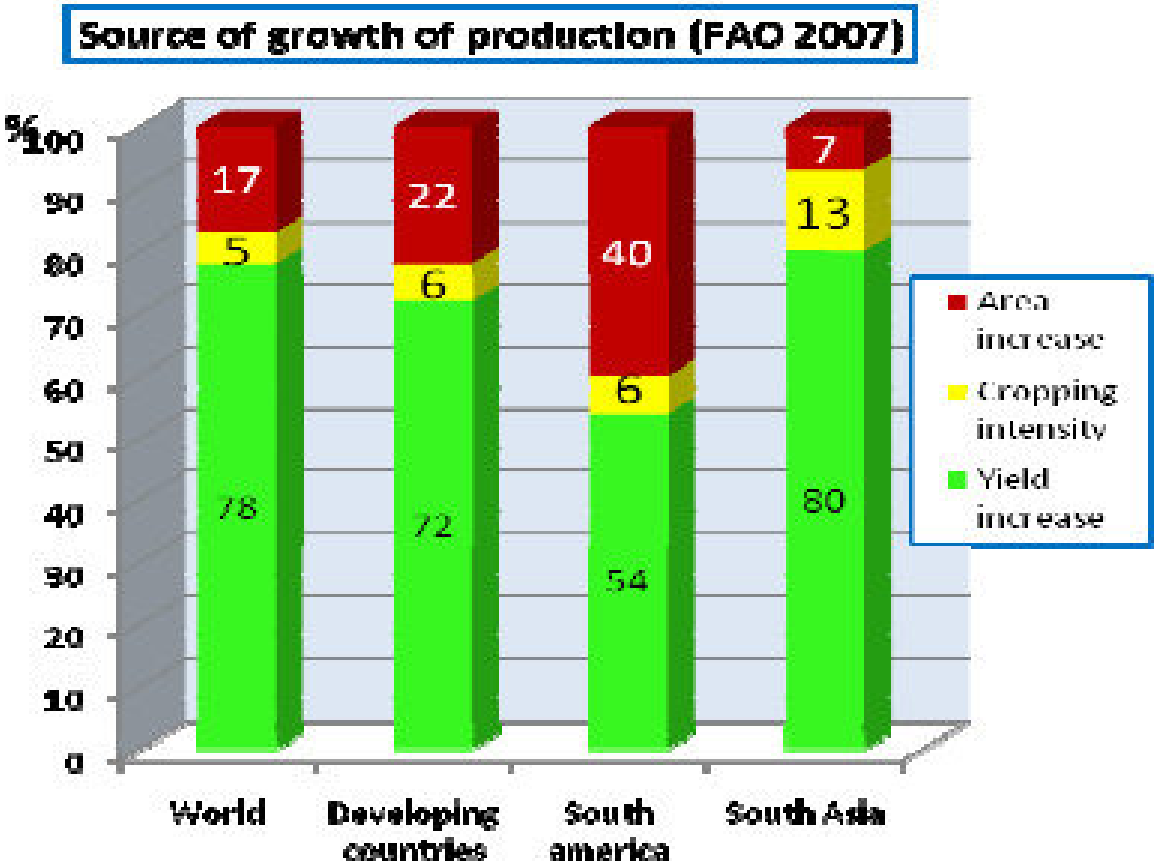


Increasing Land Demand

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Sources of growth of production

Source: TIMAC AGRO

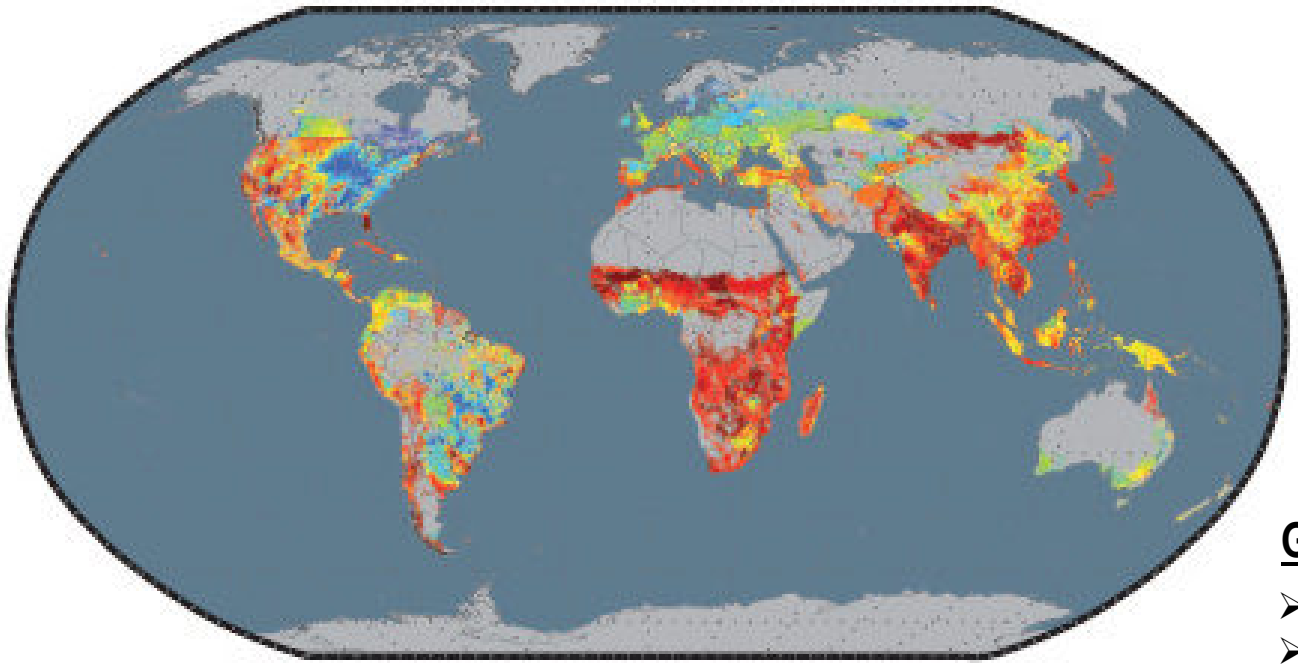


Increasing Land Demand

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Allocation of cropland to different uses in 2000

Foley et al. (2011)
Nature 476:337-342



Direct Food production area as fraction of total cropland

Global allocation of cropland area:

- Direct food production 62%
- Other crop uses
  - Anmial feed 35%
  - Bioenergy crops, seeds, other industrial products 3%

Increasing Land Demand

Meeting goals of food security & environmental sustainability

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Foley et al. (2011)
Nature 476:337-342

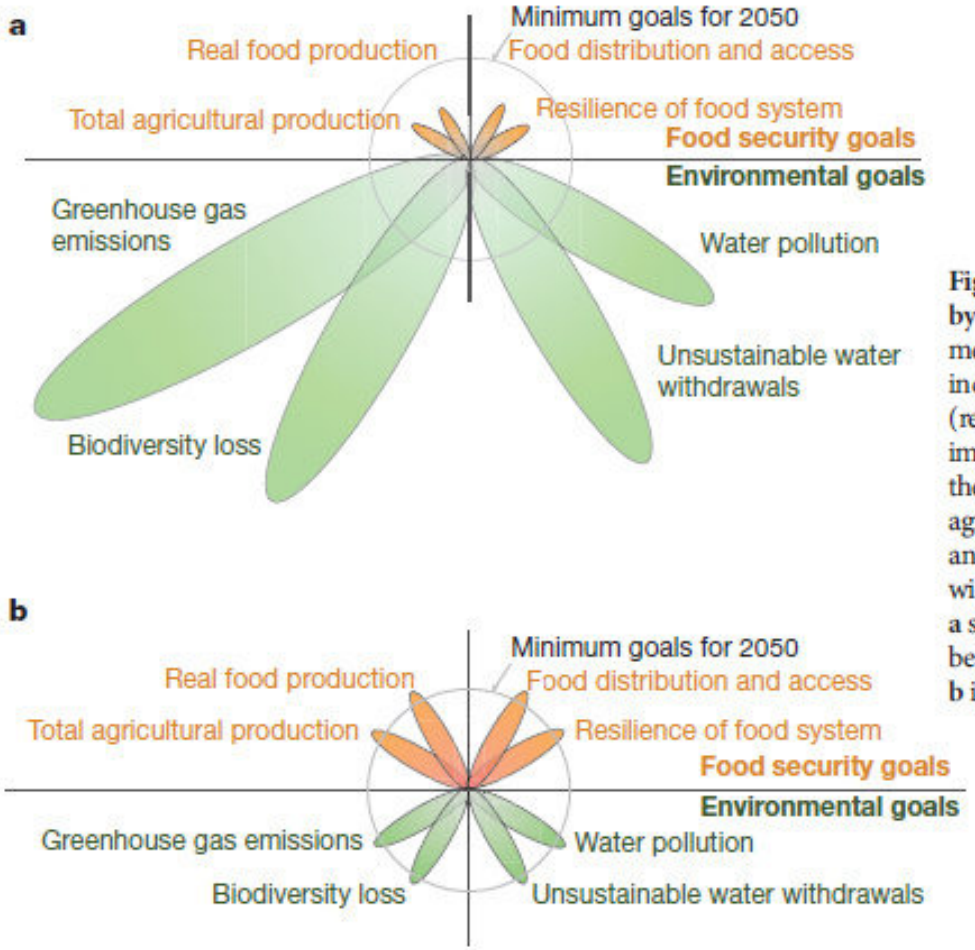


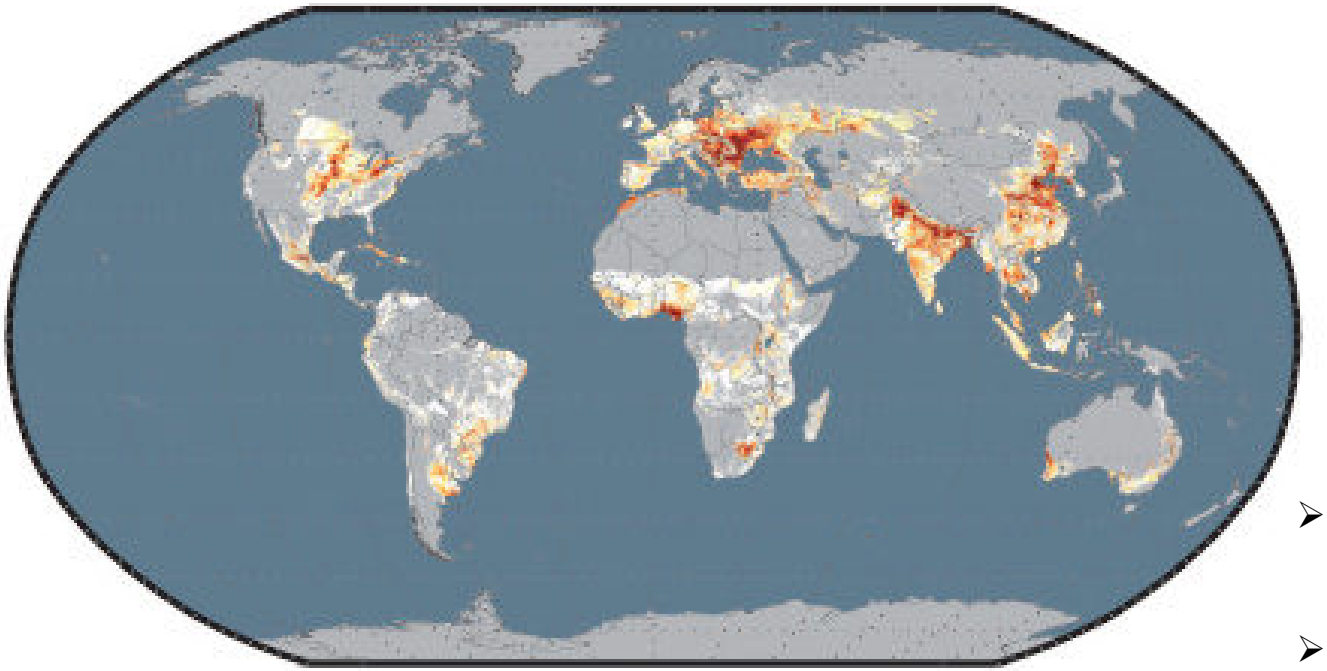
Figure 2 | Meeting goals for food security and environmental sustainability by 2050. Here we qualitatively illustrate a subset of the goals agriculture must meet in the coming decades. At the top, we outline four key food security goals: increasing total agricultural production, increasing the supply of food (recognizing that agricultural yields are not always equivalent to food), improving the distribution of and access to food, and increasing the resilience of the whole food system. At the bottom, we illustrate four key environmental goals agriculture must also meet: reducing greenhouse gas emissions from agriculture and land use, reducing biodiversity loss, phasing out unsustainable water withdrawals, and curtailing air and water pollution from agriculture. Panel **a** sketches out a qualitative assessment of how current agricultural systems may be measured against these criteria compared to goals set for 2050. Panel **b** illustrates a hypothetical situation in which we meet all of these goals by 2050.

Increasing Land Demand

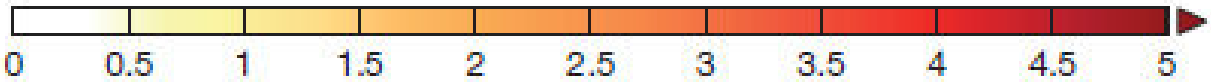
University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Closing global yield gaps of 16 major crops

Foley et al. (2011)
Nature 476:337-342



New calories from closing yield gaps for staple crops
($\times 10^6$ kcal per hectare)



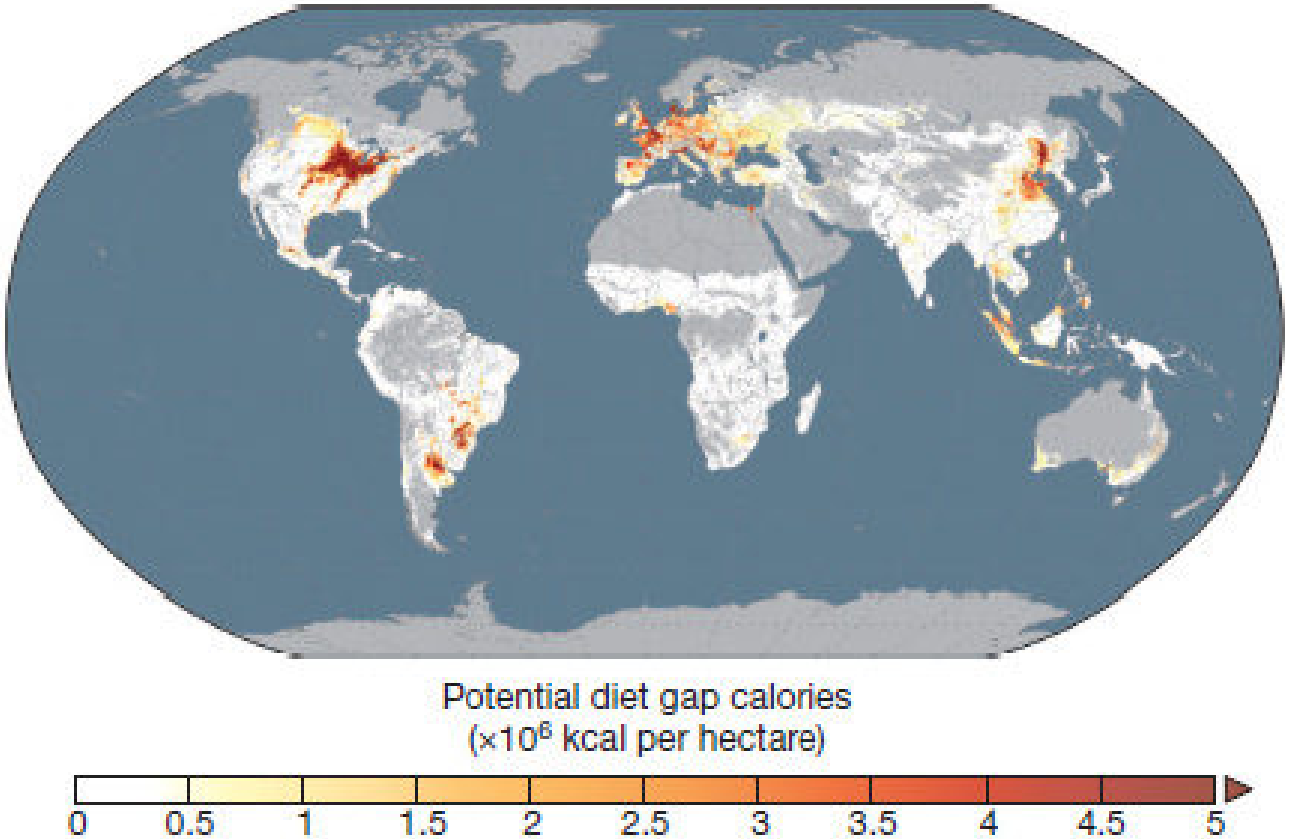
- Bringing the world´s yields to within 95% of their potential for 16 important food and feed crops
- by improving nurtient & water supplies in low-yielding regions
- adds 2.3 billion tonnes (5×10^{15} kcal)
- = 58% increase

Increasing Land Demand

Closing the "diet gap" by shifting 16 major crops to 100% human food - away from current mixes of uses

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Foley et al. (2011)
Nature 476:337-342



- Could add over a billion tonnes to global food production
- Representing a 28% increase for those 16 crops
- Equivalent of $3x10^{15}$ kcal more food to global diet (49% increase in food calories delivered)

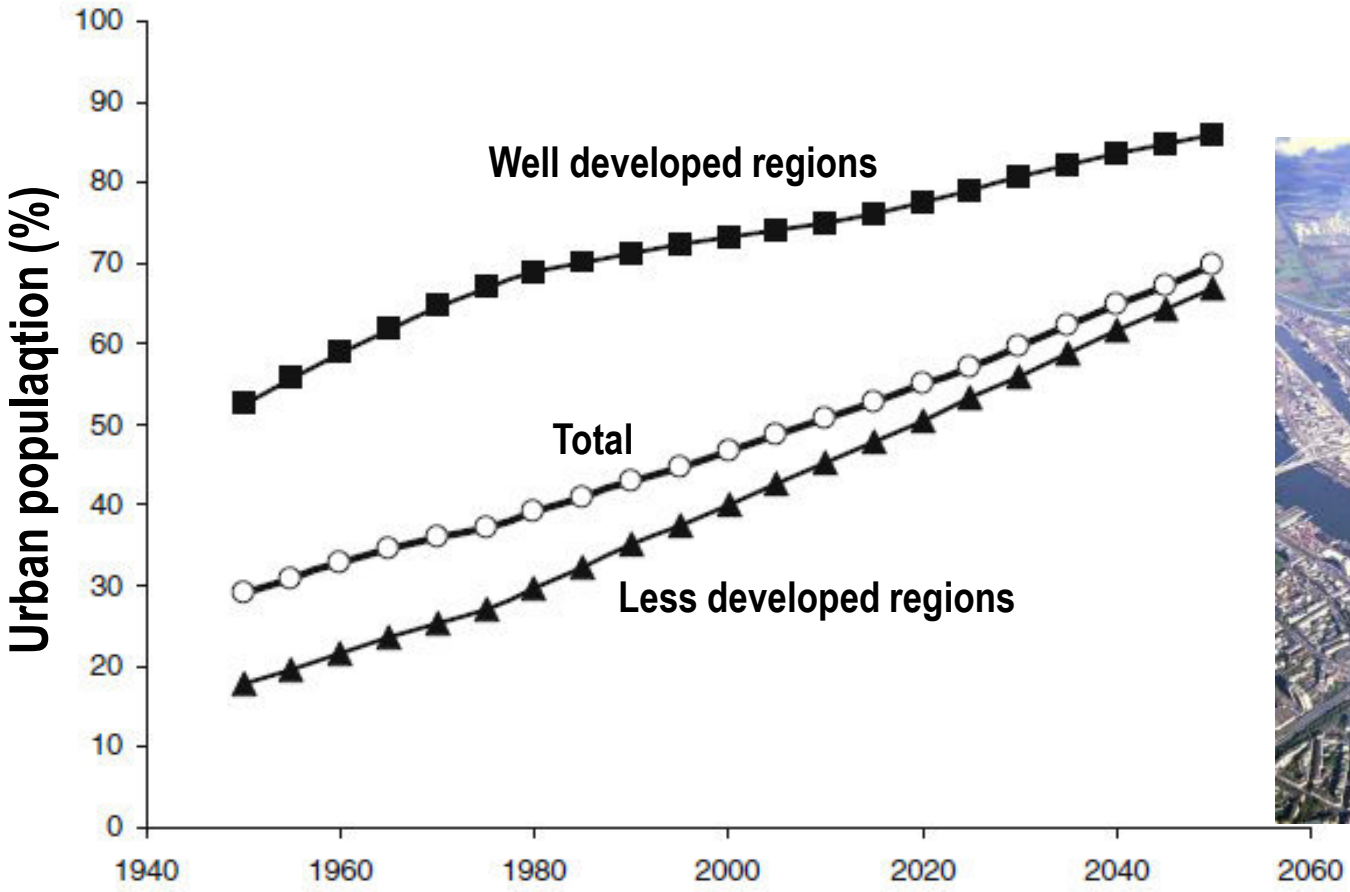
Urbanisation

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Ever increasing agglomeration in urban areas

- Proportion of people living in urban areas (global)

Ajmone-Marsan & Biasioli (2008)
Water, Air Soil Pollution 213:121-143



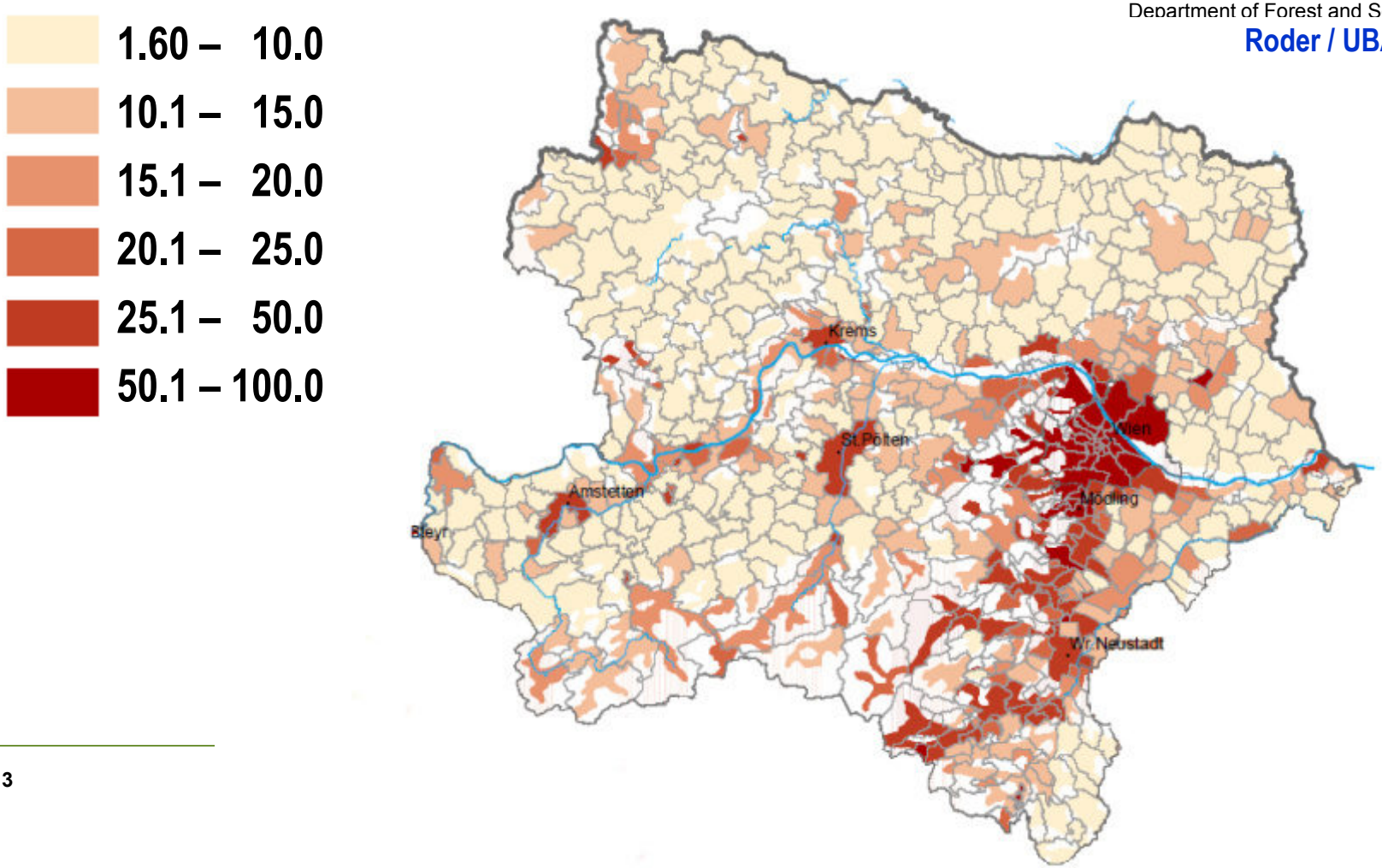
Urbanisation

Ever increasing agglomeration in urban areas

- Land consumption in % of permanent settlement space (Lower Austria)

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Roder / UBA (2003)



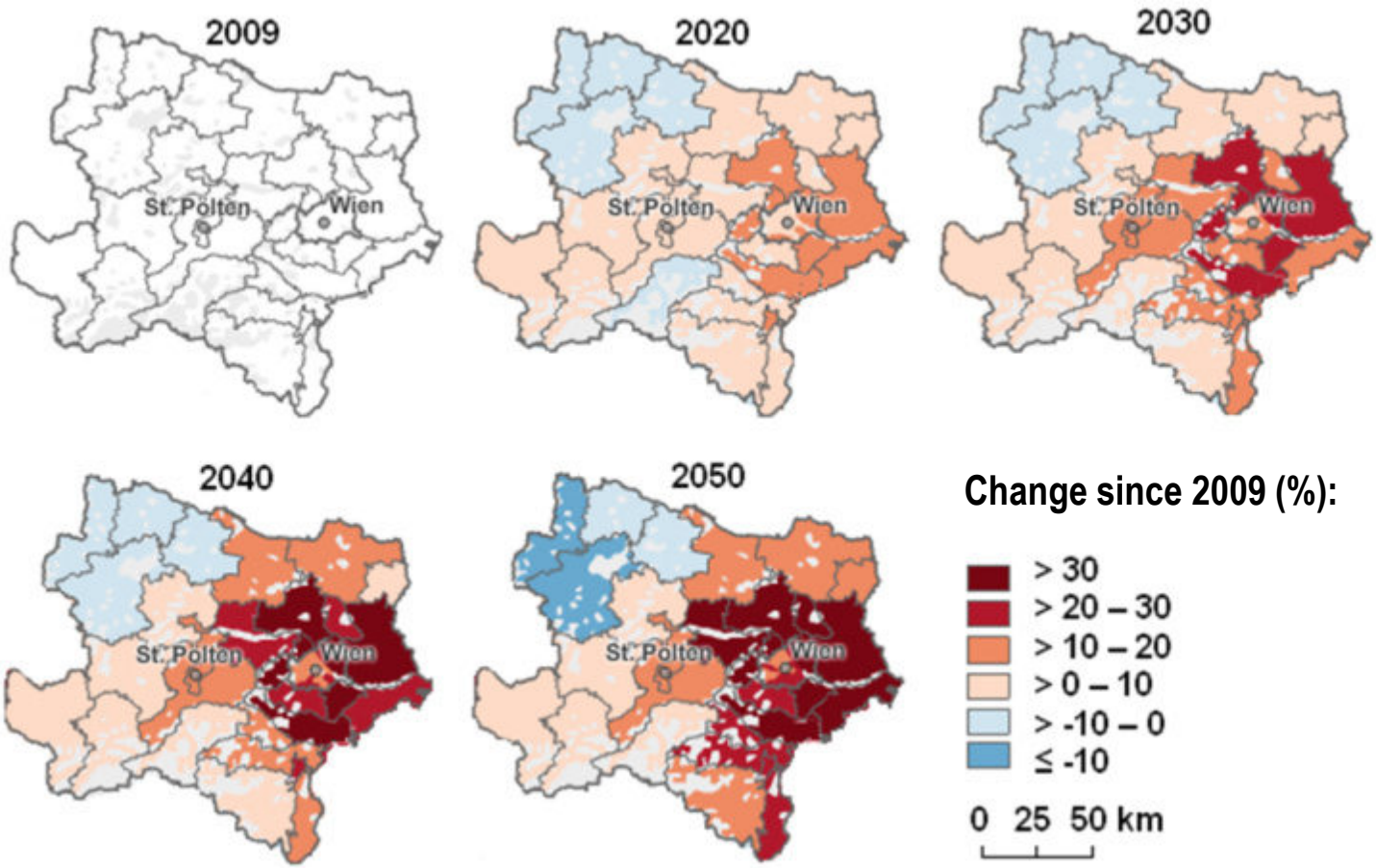
Urbanisation

Ever increasing agglomeration in urban areas

- Projected population changes in Lower Austria until 2050

niversity of Natural Resources
nd Life Sciences
epartment of Forest and Soil Sciences

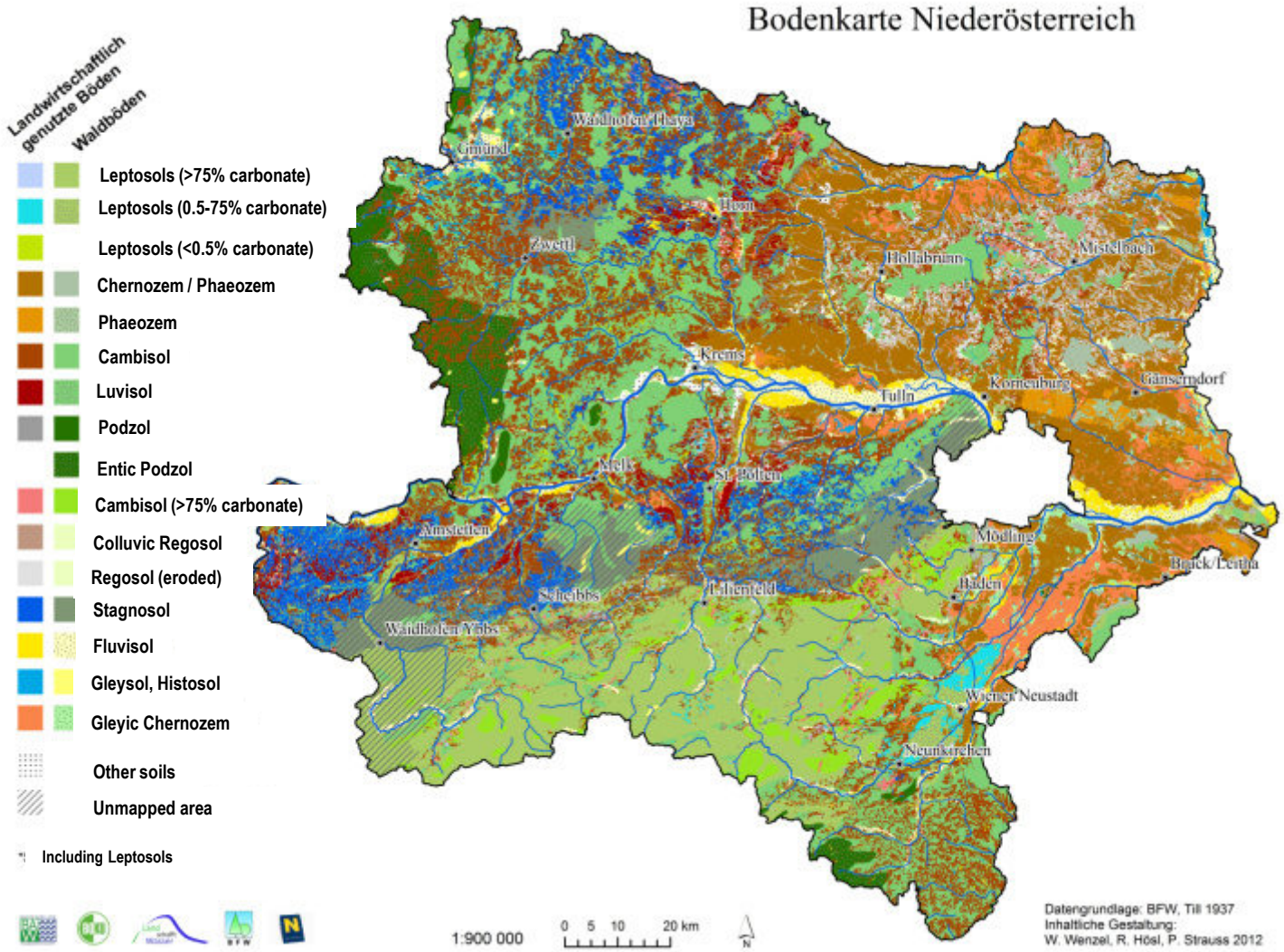
Statistik Austria (2010)



Urbanisation

Ever increasing agglomeration in urban areas

- Soil map of Lower Austria



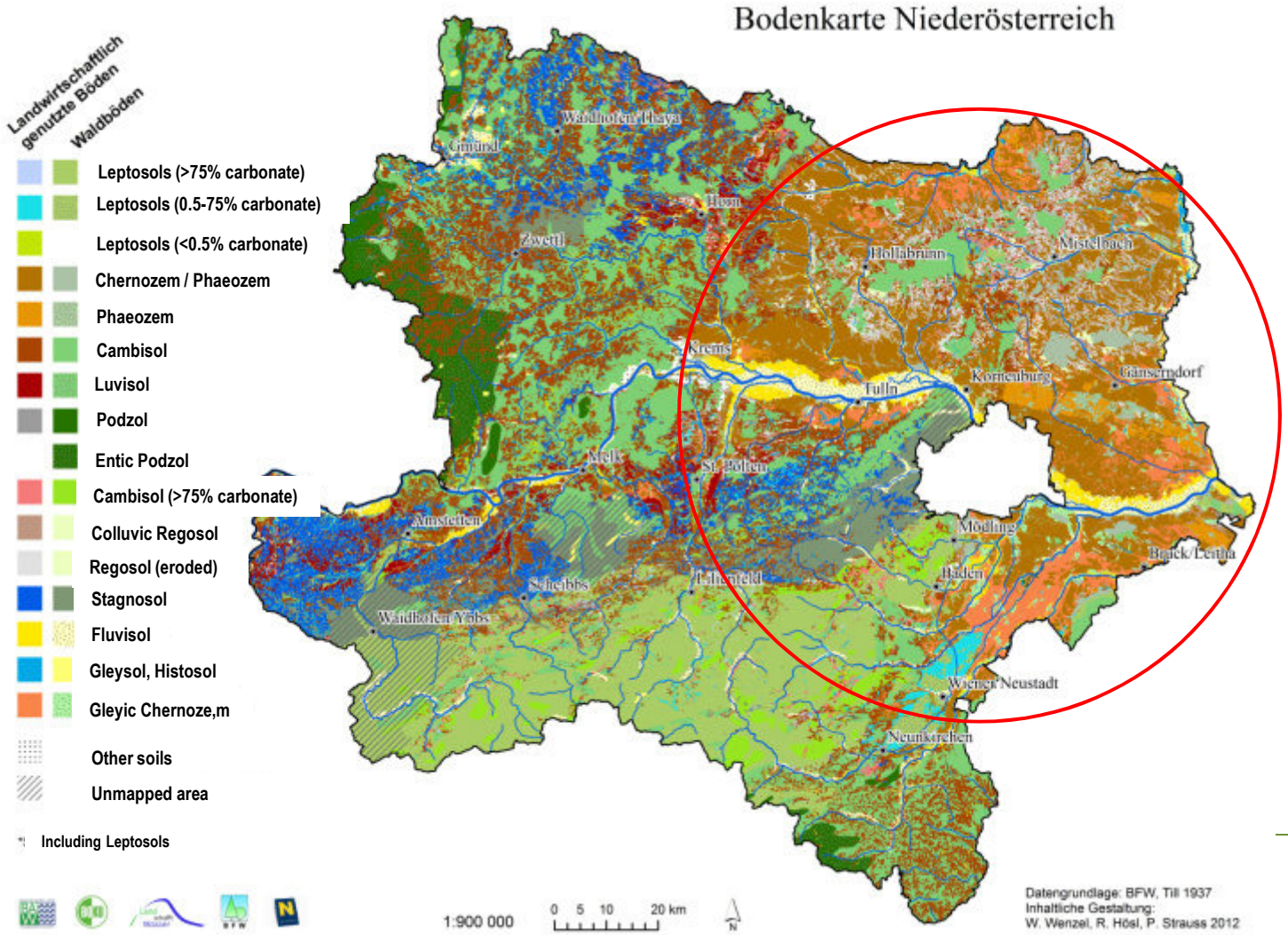
University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Wenzel et al. (2012)

Urbanisation

Ever increasing agglomeration in urban areas

- Soil map of Lower Austria



The most fertile soils overlap with the largest projected increases of population

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Wenzel et al. (2012)

Soil compaction

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Photo: W.W. Wenzel 2006

Photo: W.W. Wenzel 2006

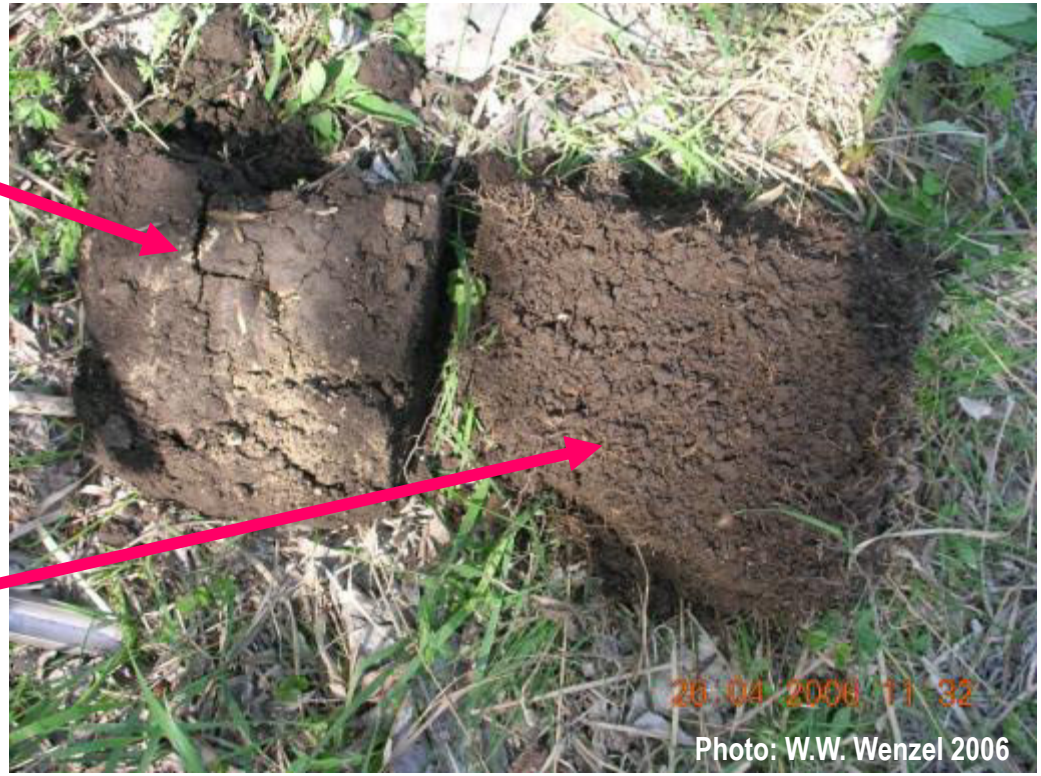


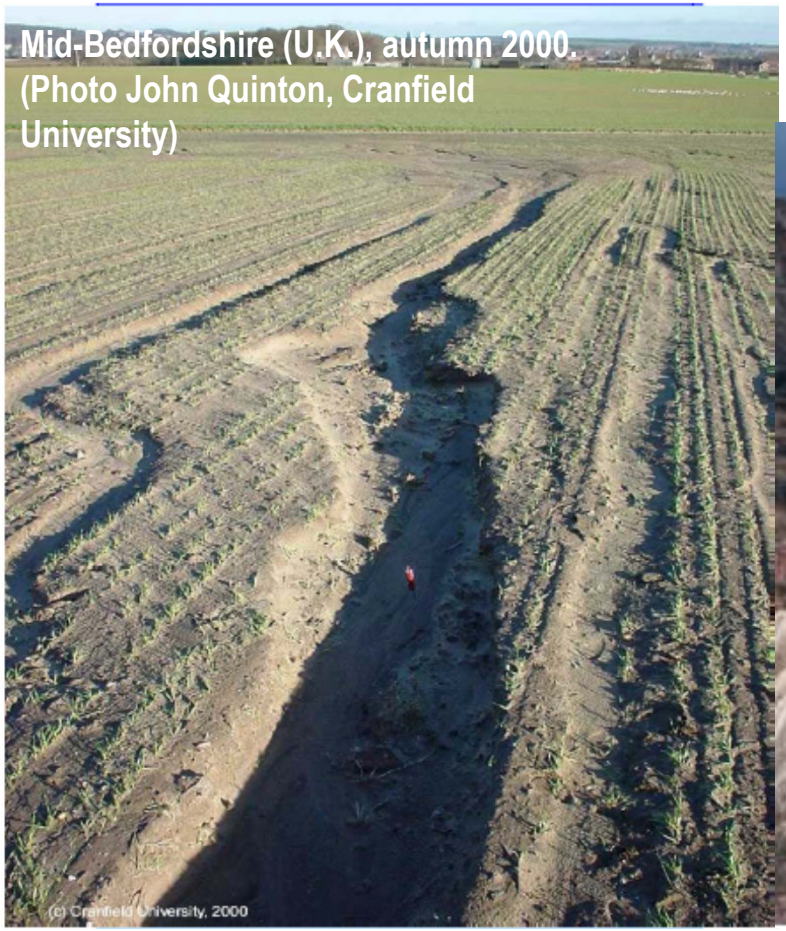
Photo: W.W. Wenzel 2006

Soil Erosion

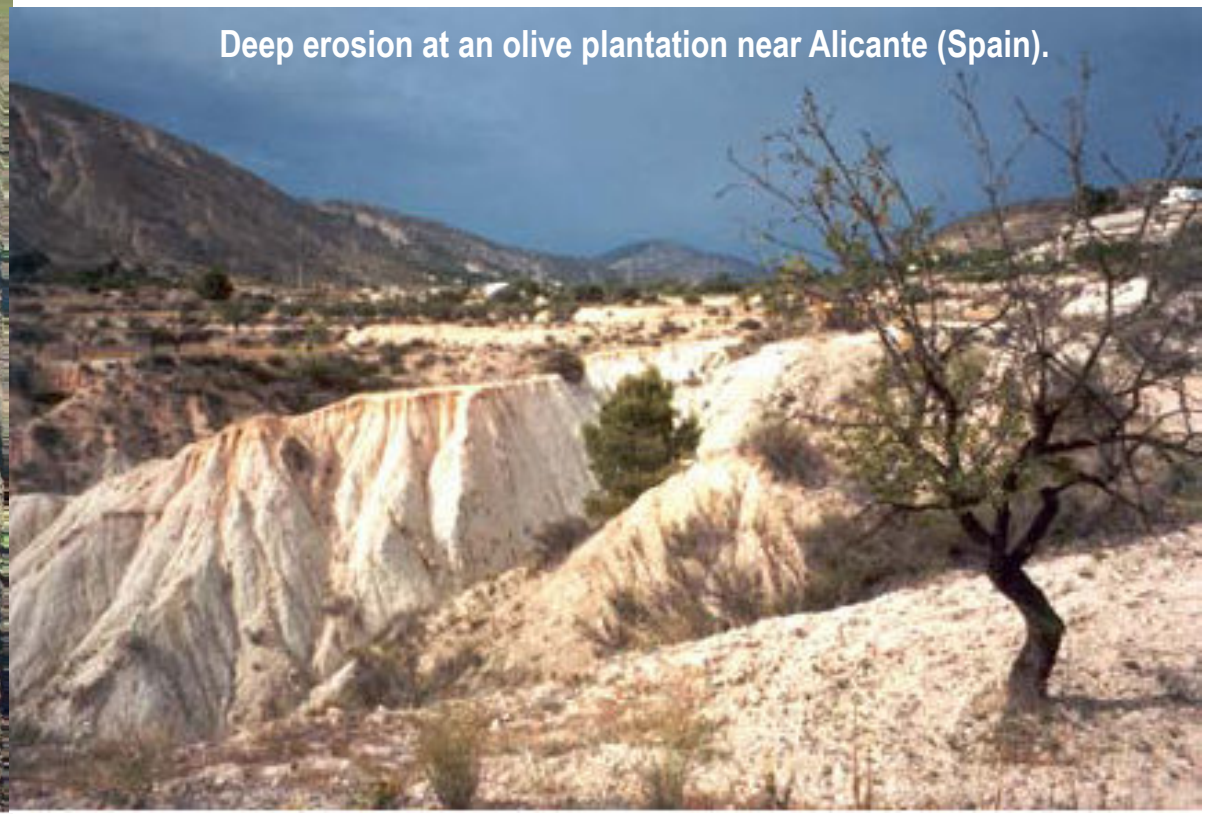
Grimm et al. (2002): Soil erosion risk in Europe.
JRC Ispra.

Kirkby et al. (2004): Pan-European soil erosion risk assessment.
Special Publication Ispra No. 73 (S.P.I.04.73).

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences



Mid-Bedfordshire (U.K.), autumn 2000.
(Photo John Quinton, Cranfield University)



Deep erosion at an olive plantation near Alicante (Spain).

Soil Erosion

Jones et al. (2003): EU Soil thematic Strategy,
TWG Soil Erosion WP2: Nature and extent of soil erosion in Europe. Annex 1.

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Winderosionsereignis in Norddeutschland.

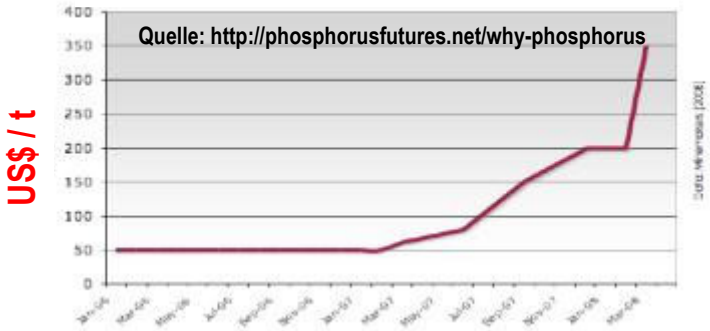
Phosphorus

P resources at risk?

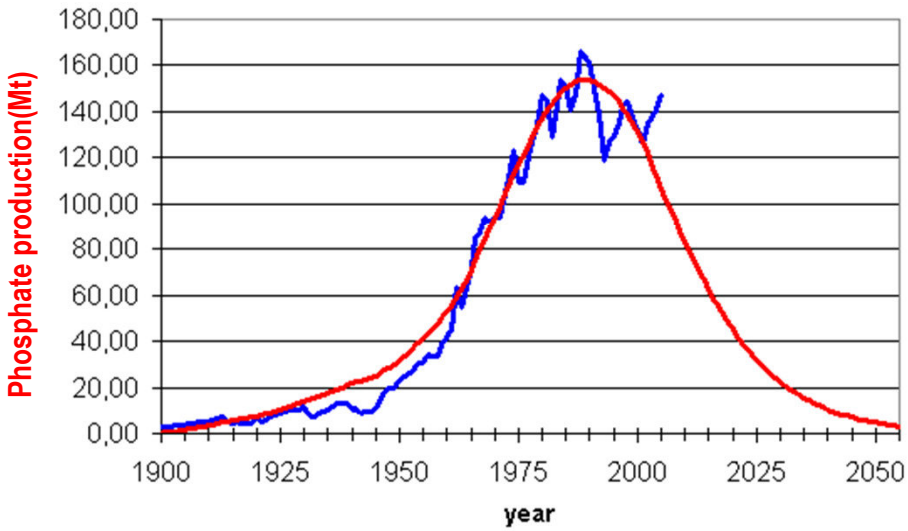
- Decline of P resources (peak P)
- P fertiliser prices increase

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

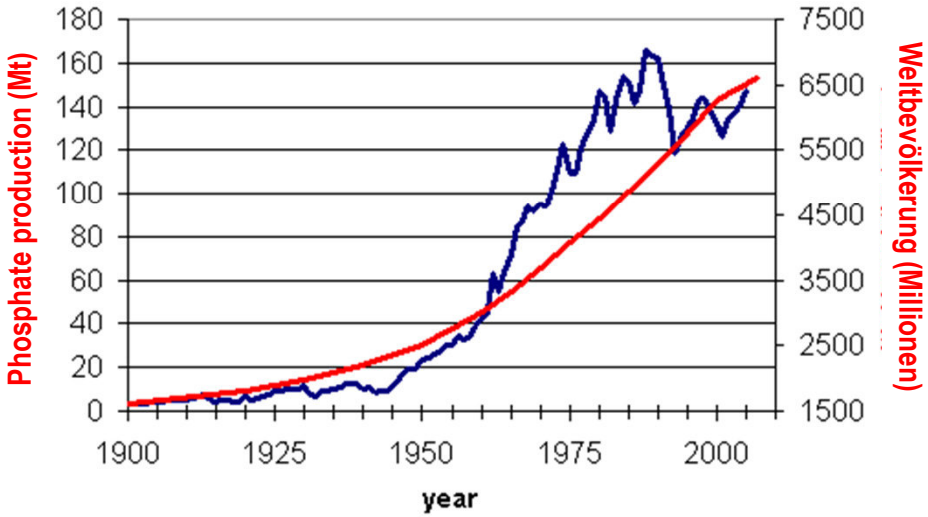
Rock phosphate commodity price



Global phosphate production



Global phosphate production versus population growth



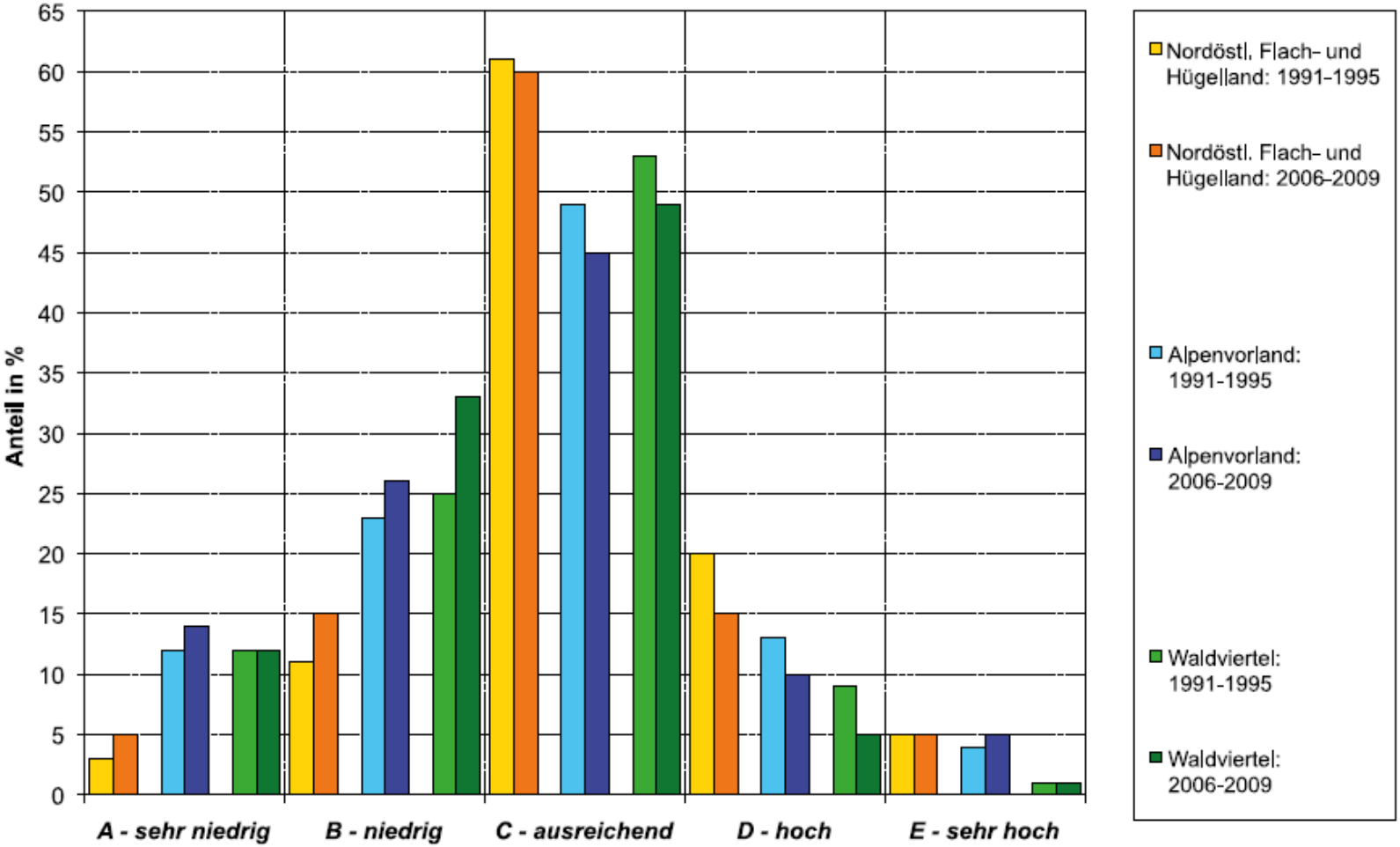
Quelle: http://www.energybulletin.net/node/33164

Phosphorus

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

P status of soils

- P availability in soils of various production regions of Austria



AGES (2011)
Bodenschutz durch umweltgerechte Landwirtschaft. AGES, Wien

Phosphorus

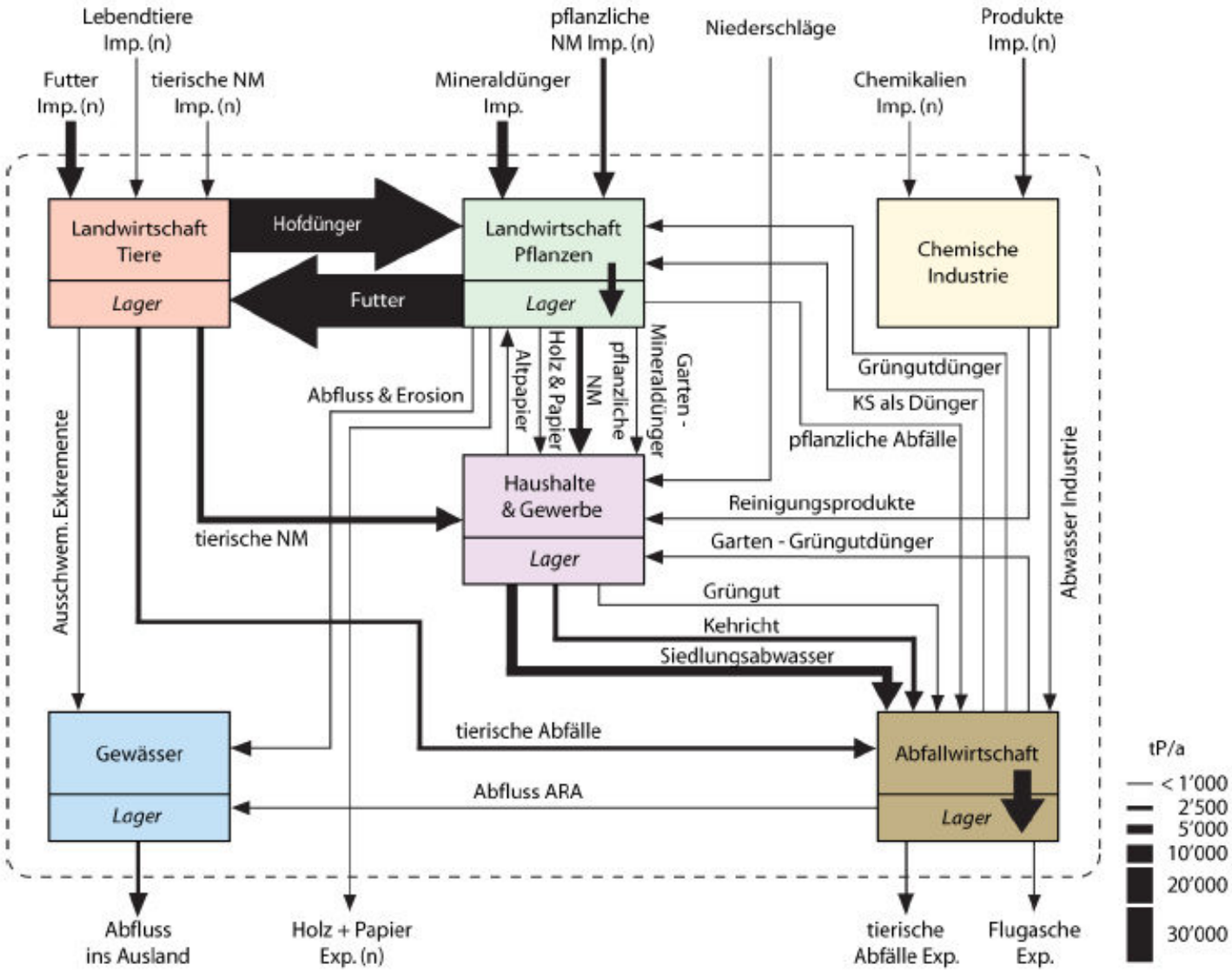
P losses and eutrophication

- Soil erosion
- Water pollution

Phosphorus

P resources at risk?

- Modelled P fluxes in Switzerland (main system)



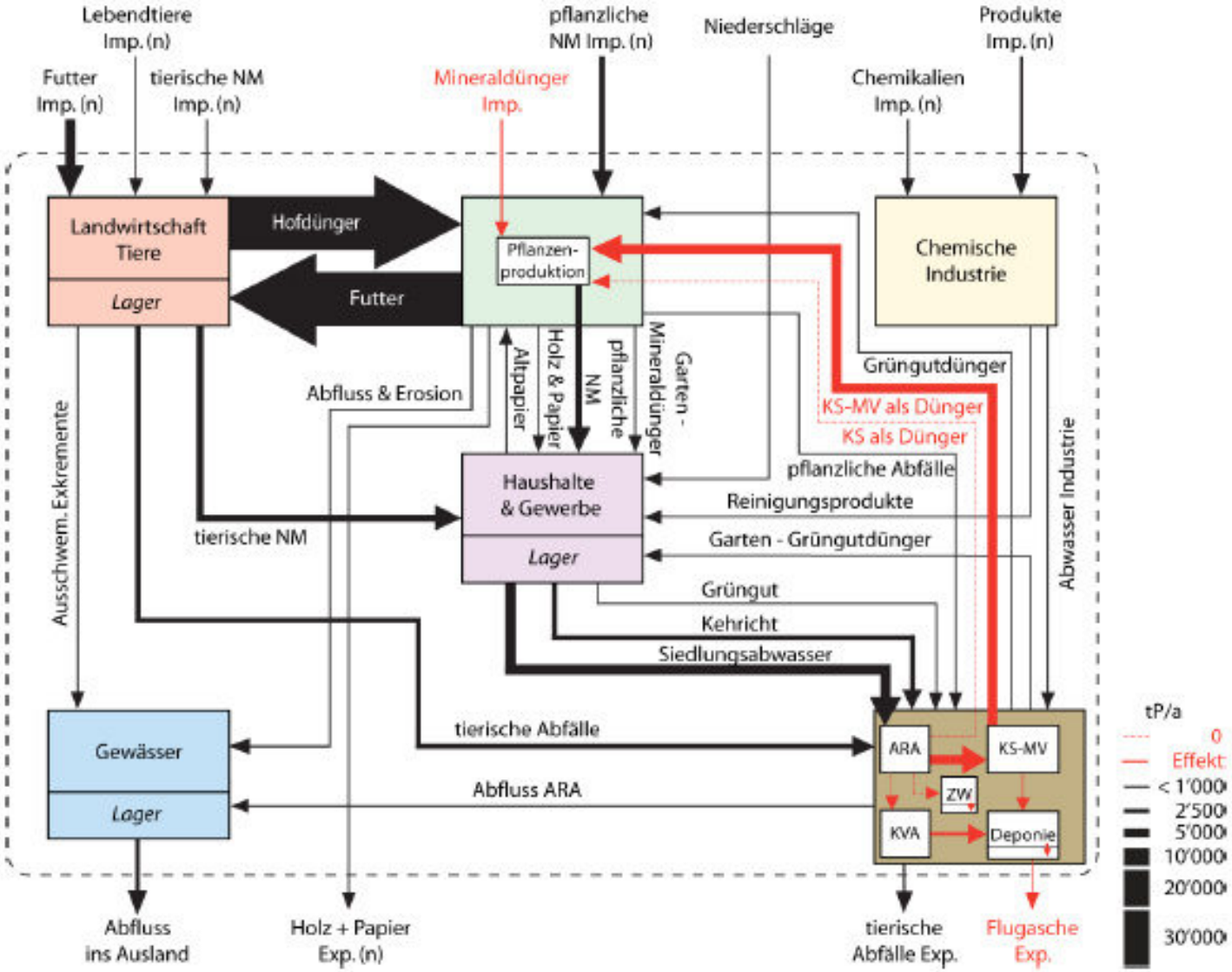
University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Binder et al. (2009)
Phosphorflüsse der Schweiz.
Bundesamt für Umwelt, Bern.

Phosphorus

P resources at risk?

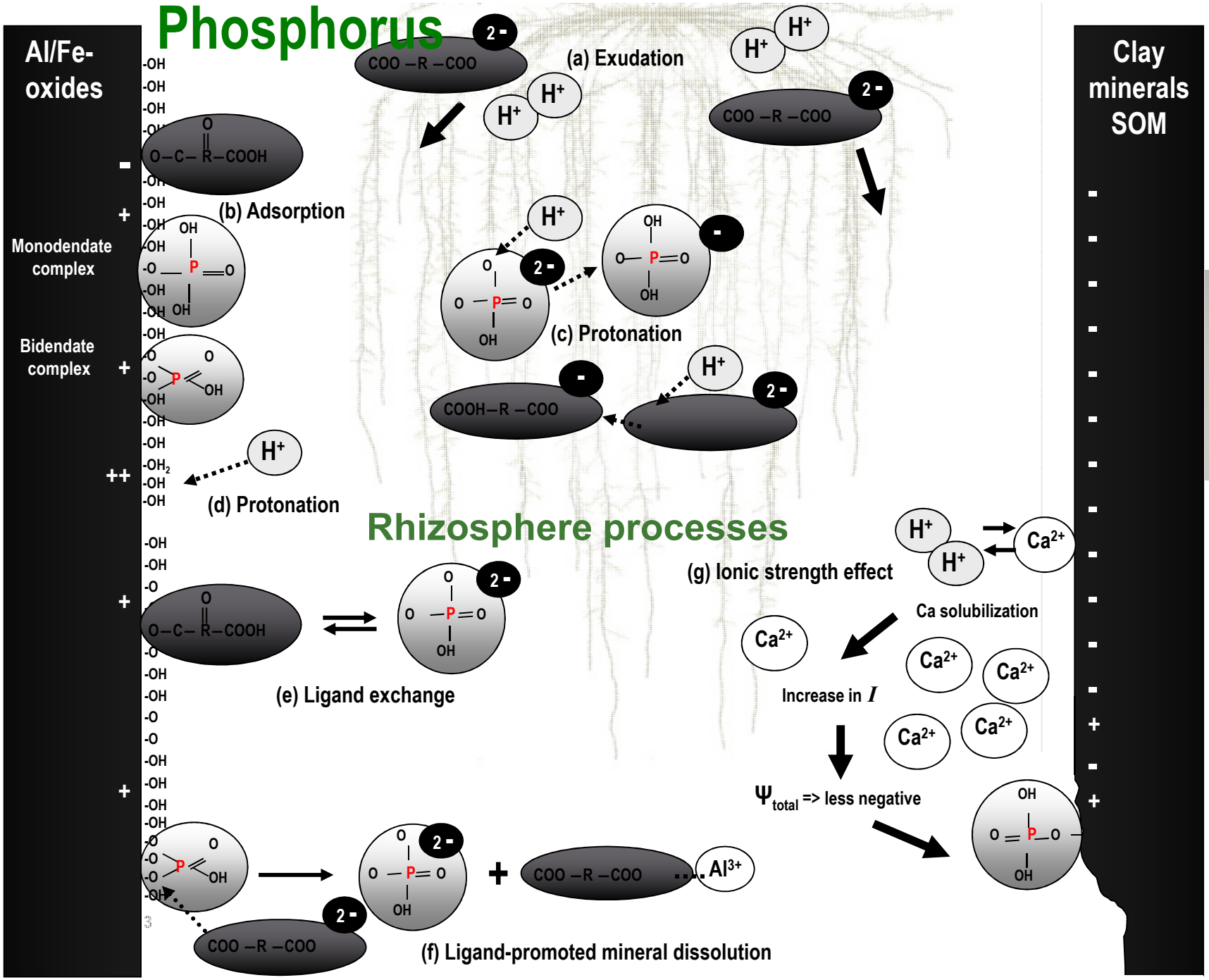
- Scenario “recycling of sewage sludge P”



University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Binder et al. (2009)
Phosphorflüsse der Schweiz.
Bundesamt für Umwelt, Bern.

Phosphorus



Oburger et al. (2011) Plant & Soil. 341:363-382

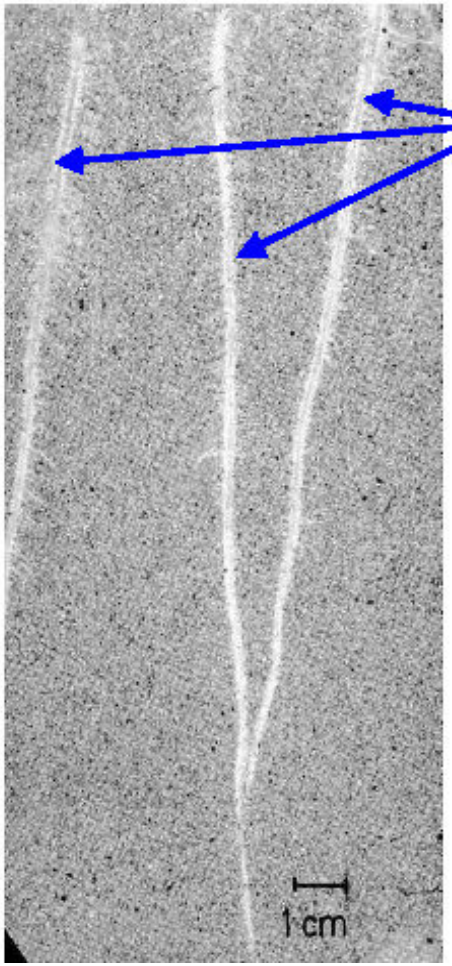
Phosphorus

Phosphorus use efficiency

- High resolution mapping of total P in teh rhizosphere

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Jungk (1996): In Plant roots. The hidden half.



Autoradiograph of maize roots in a soil labelled with radioactive P (^{33}P)
(Jungk, 1996 - In : Plant Roots The Hidden Half)

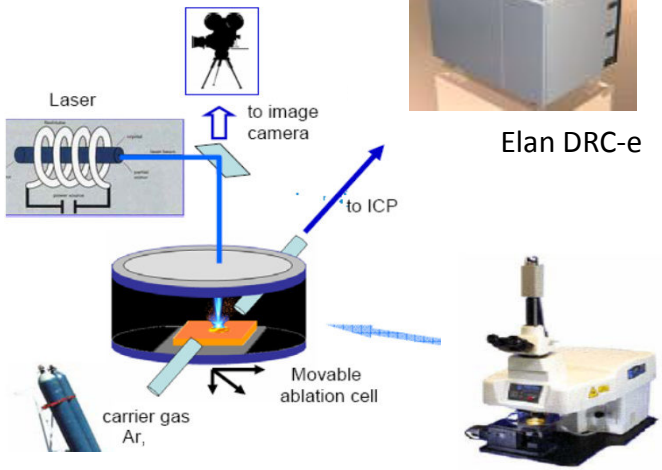
see also Lewis & Quirk (1967) , Bhat & Nye (1973), Hendriks et al. (1981), Kraus et al. (1987), Hübel & Beck (1993)

Phosphorus

P use efficiency

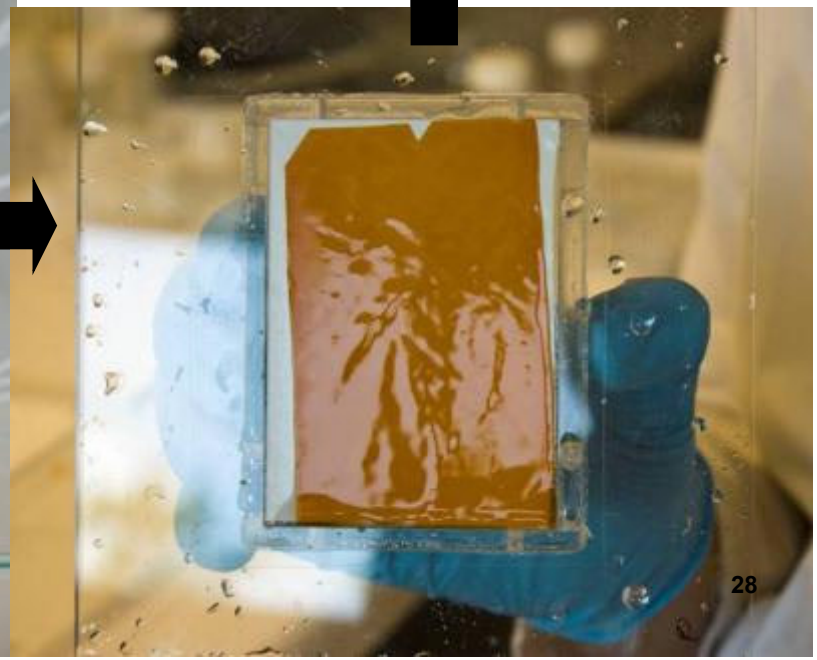
- Rhizotron experiment
- Diffusive gradients in thin films (DGT)
- Laser ablation ICP-MS

Santner et al. (2012)
Environ. Exper. Bot. 77:219-226



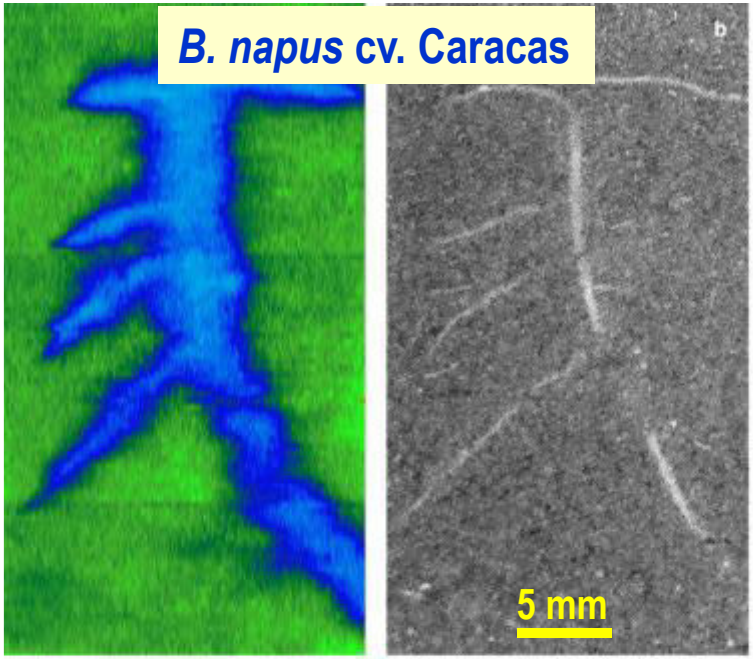
Elan DRC-e

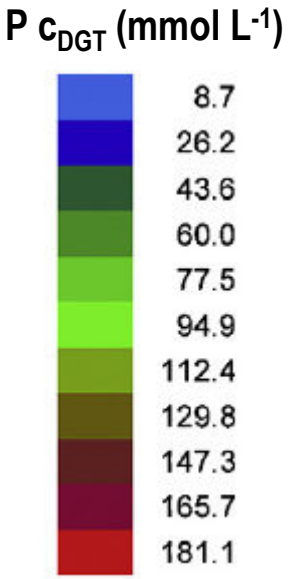
New wave UP-193

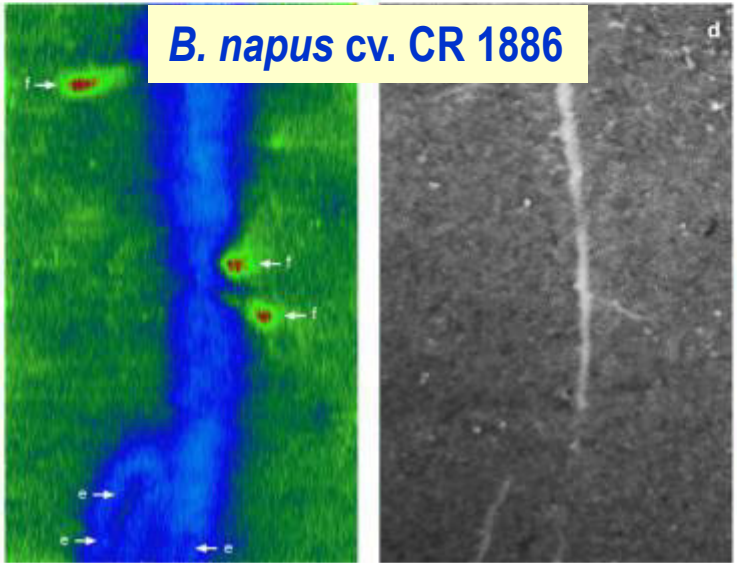


Phosphorus

Santner et al. (2012)
Environ. Exper. Bot. 77:219-226

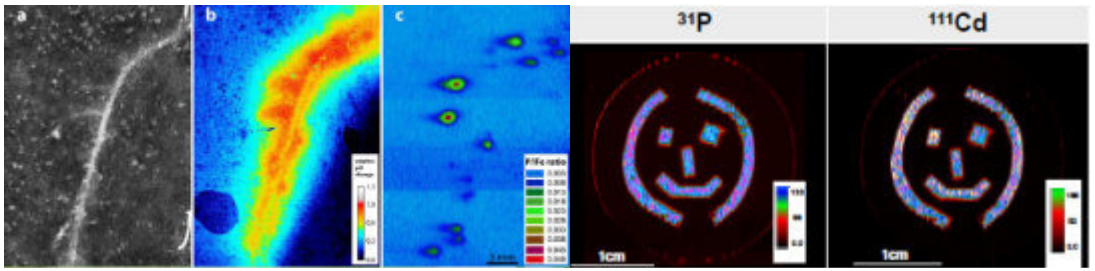






P use efficiency

- High-resolution mapping of P availability in the rhizosphere based on DGT flux measurement
- Variability among rape cultivars
- Phenotyping of cultivars regarding P use efficiency
- Further developments: DGT gels forr P, Fe, Al, Ca, planar optodes for pH



Soil Pollution

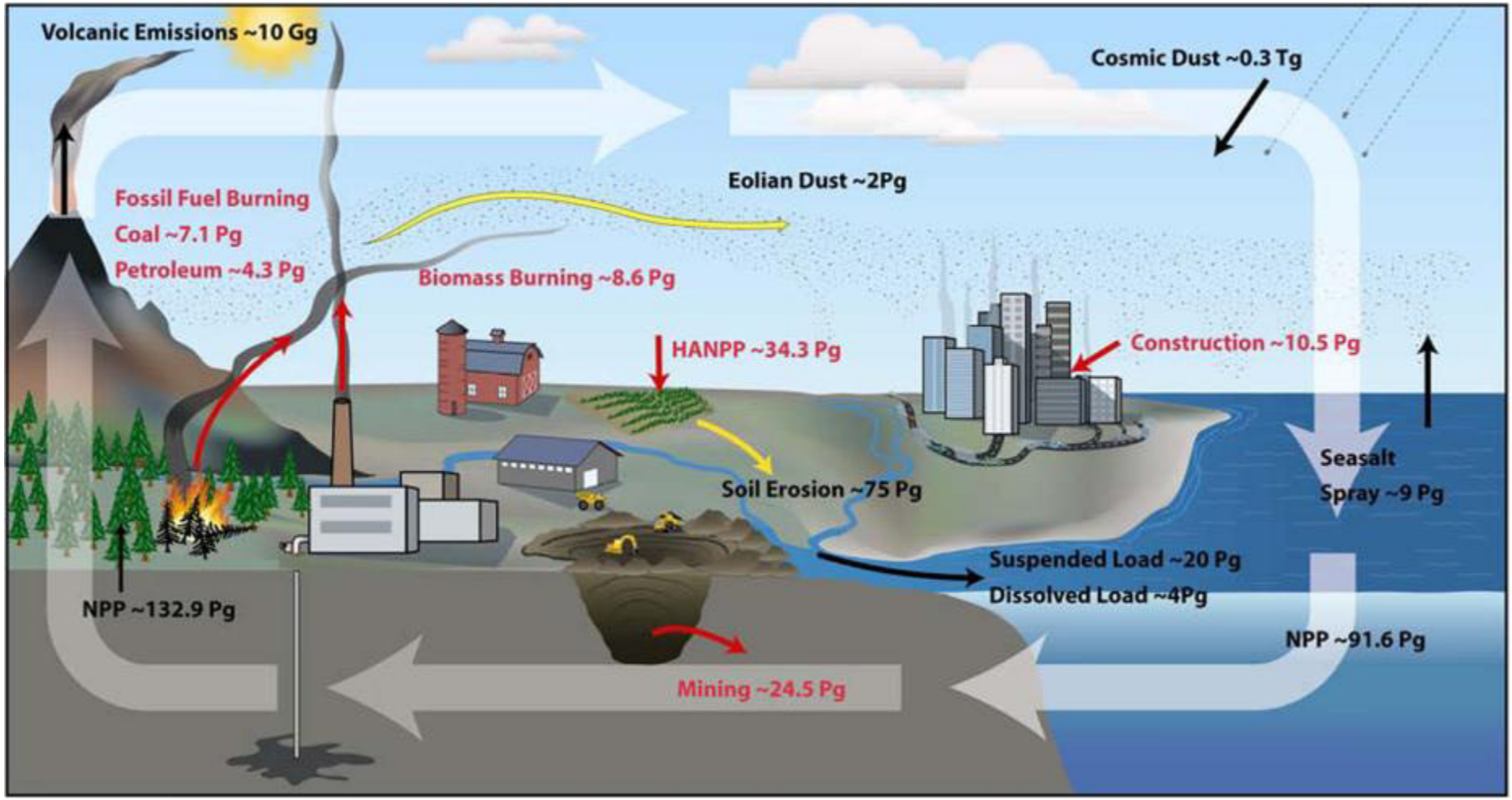
1 Gg = 10^9 g = 1000 t
1 Tg = 10^{12} g = 1 Mio. t
1 Pg = 10^{15} g = 1 Billion t

Anthropogenic versus geogenic material fluxes

- Global fluxes

Sen & Peucker-Ehrenbrinck (2012)
Environ. Sci. Technol. 46:8601-8609

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

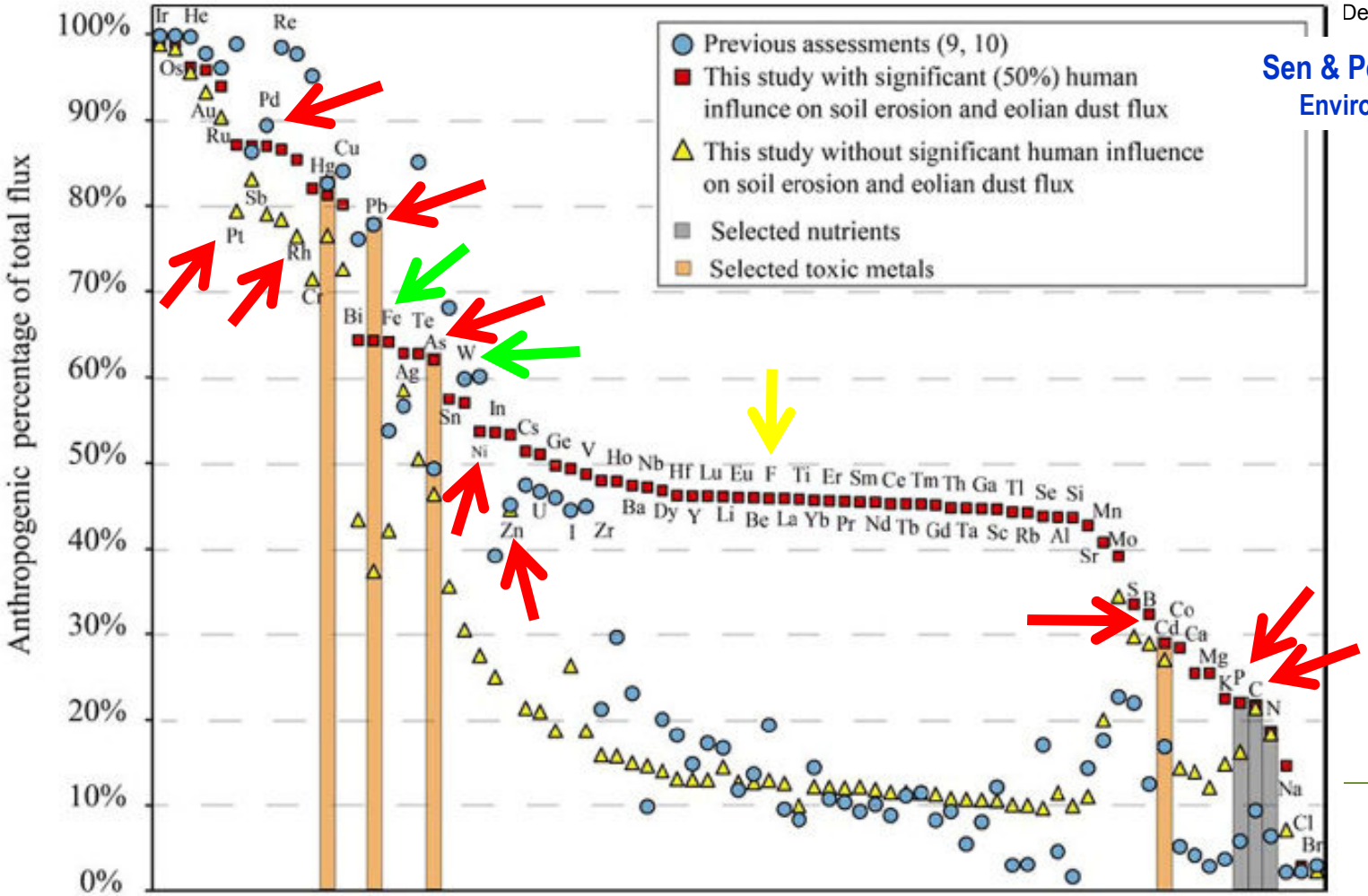


Soil Pollution

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Anthropogenic versus geogenic element fluxes

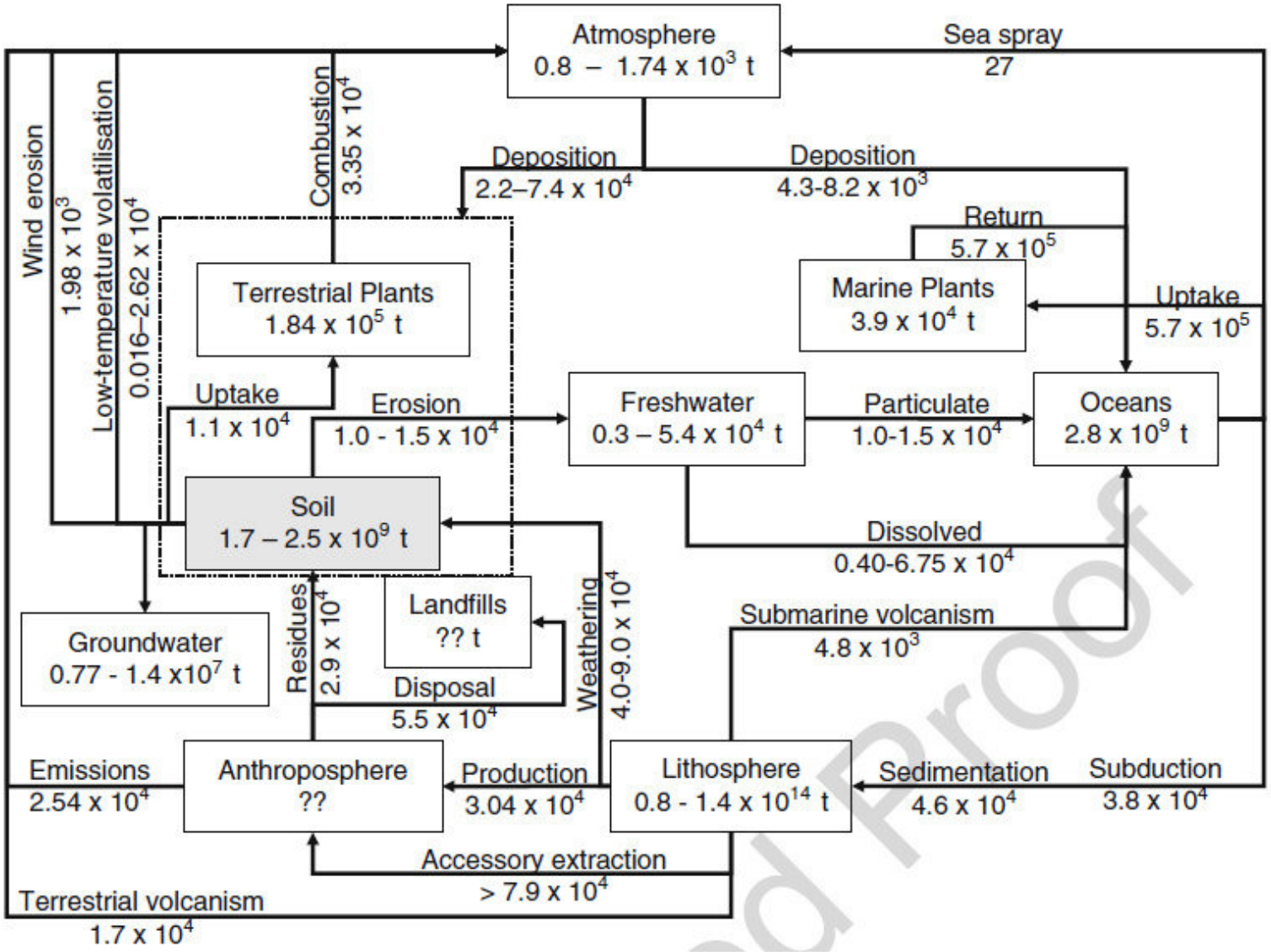
- Anthropogenic proportion on total fluxes



Sen & Peucker-Ehrenbrinck (2012)
Environ. Sci. Technol. 46:8601-8609

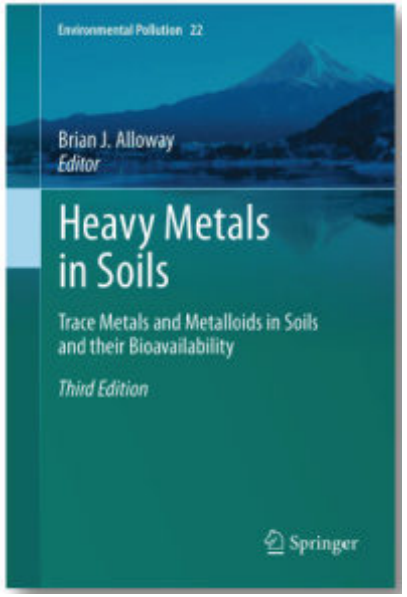
Soil Pollution

Global arsenic fluxes

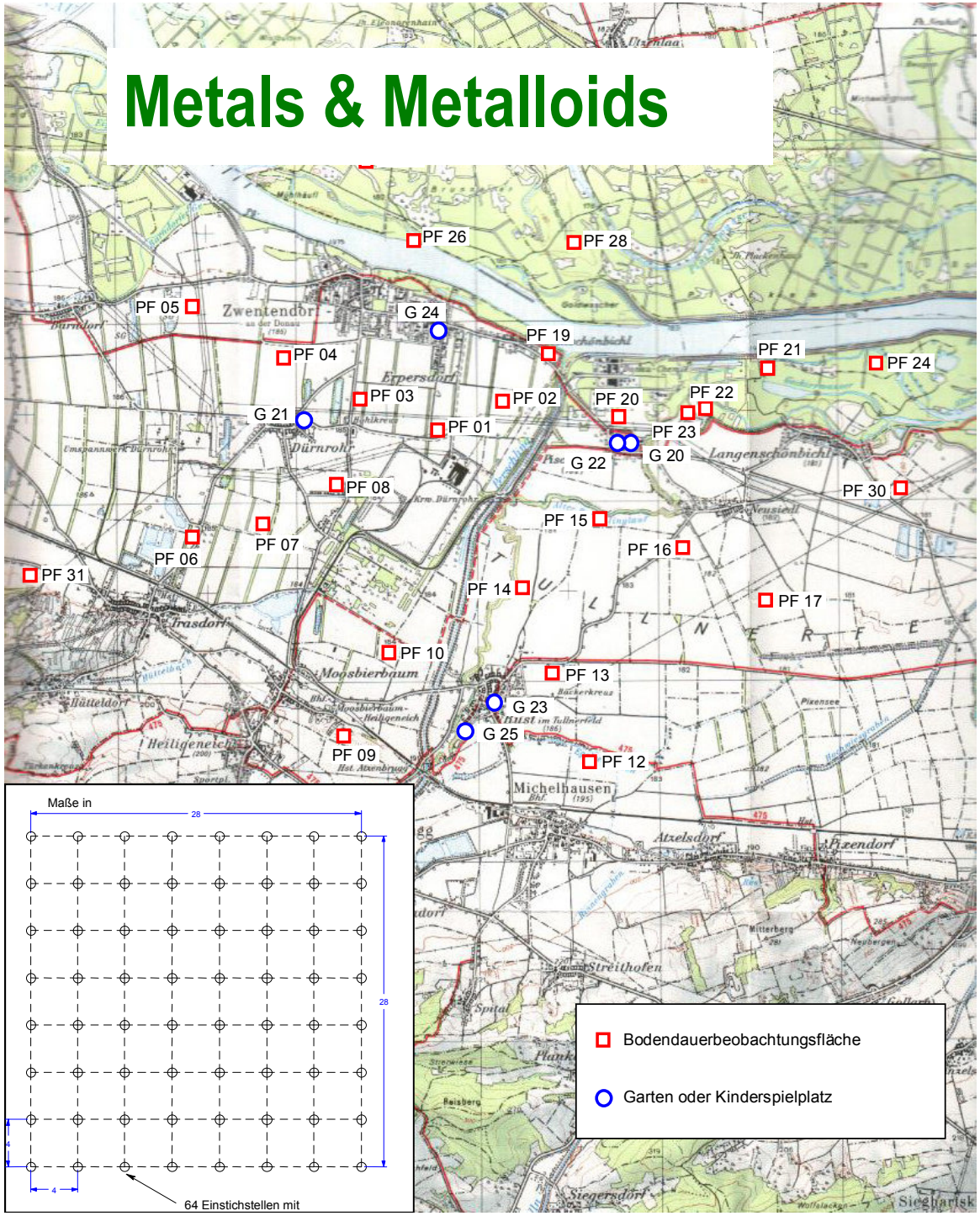


University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Wenzel (2012)
In: Alloway, Heavy Metals in Soils.



Metals & Metalloids



Wenzel & Wieshammer (2006)

Tschernosem, Zwentendorf (Quelle: Land NÖ)

Soil monitoring

- Dürnrohr (Tullner Feld)
- Soil samplings 1998 und 2003

mg kg^{-1}		Area average 2003	Area average 1998
As	MW	11,4	8,34
	SE	2,91	2,08
Cd	MW	0,235	0,457
	SE	0,048	0,239

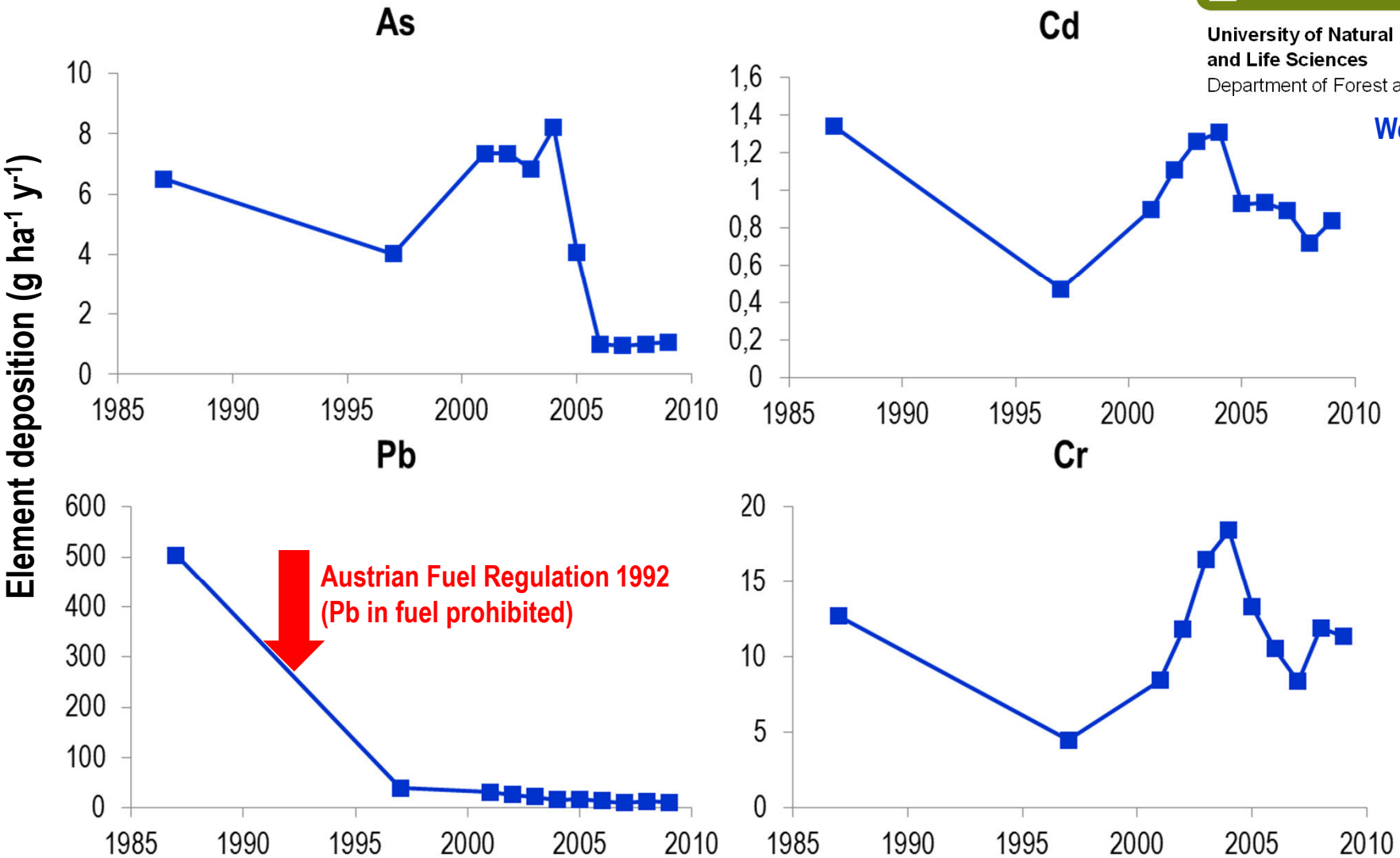
Metals & Metalloids

Element depositions in the Tullner Feld 1987-2009

- Environmental Monitoring Dürnrohr (Tullner Feld)

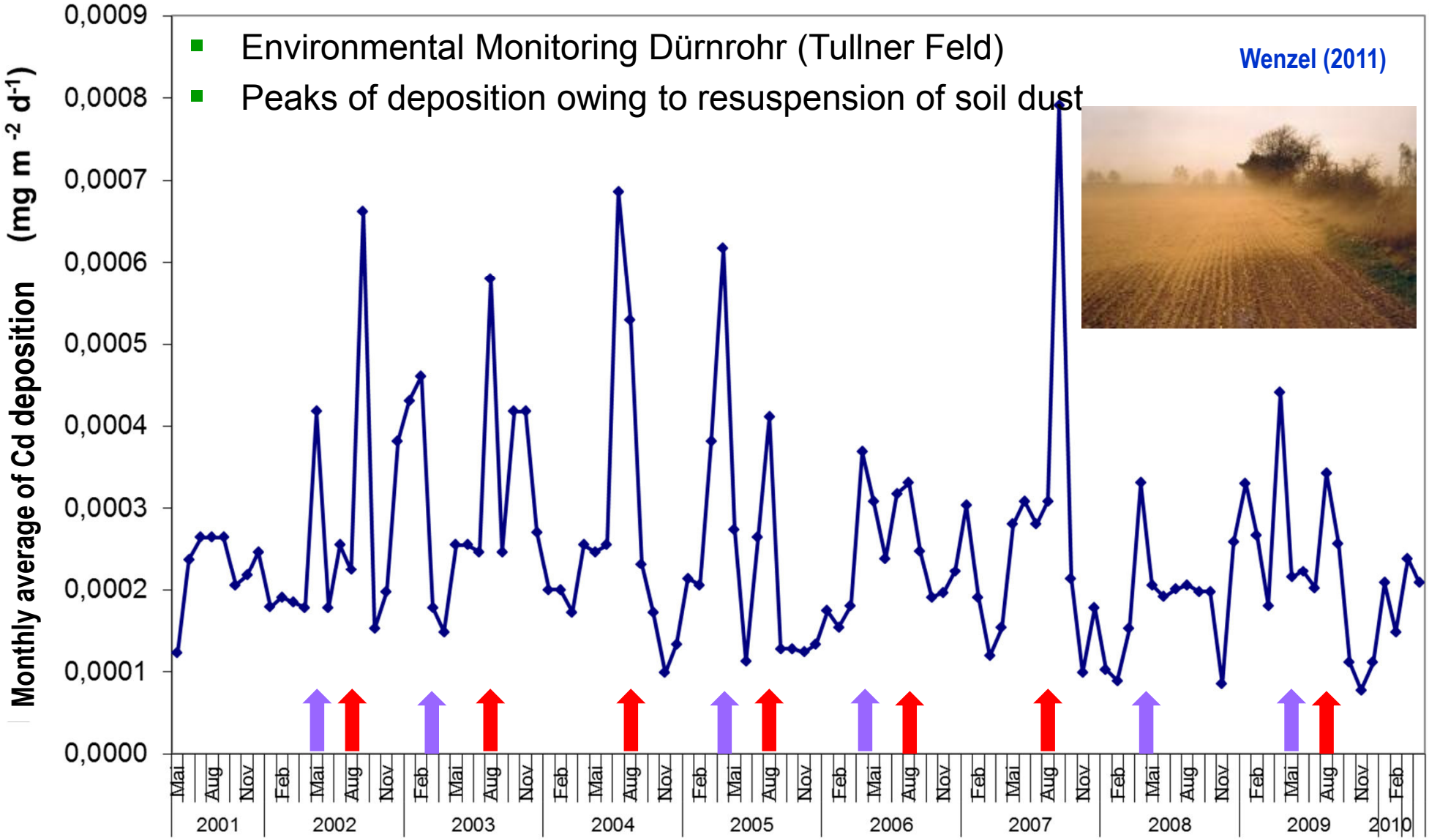
University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Wenzel (2011)



Metals & Metalloids

Monthly means of Cd deposition at site EVN

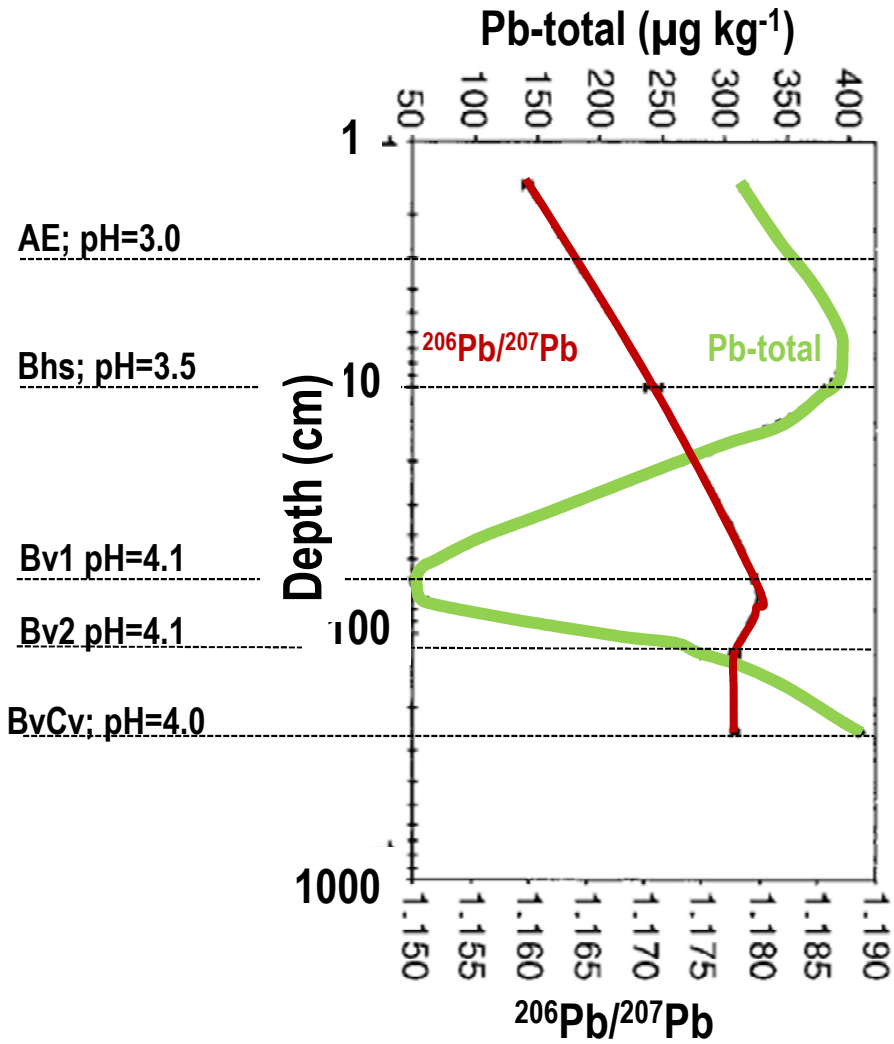


Metals & Metalloids

Lead accumulation in soils

- Isotopic ratio for tracing of sources, ICP-MS measurements
- ^{206}Pb derives from leaded antiknock additives to fuel
- Pb sources: mainly from Australian mines with narrow $^{206}Pb/^{207}Pb$ ratios

Prohaska et al. (2000)
J. Anal. Atom. Spectrom. 15: 365-369.



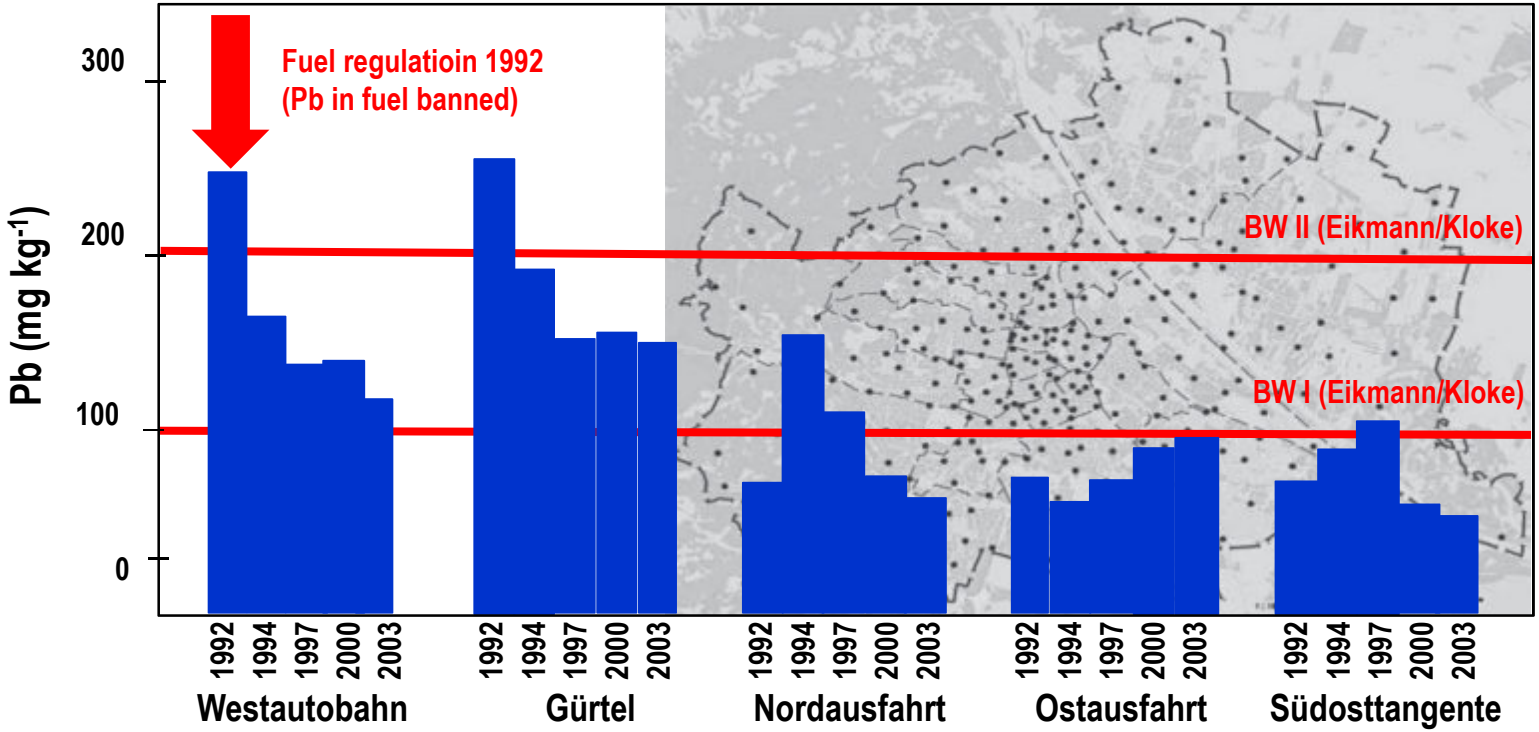
Metals & Metalloids

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Changes of Pb concentrations in urban soils (Vienna)

Wiener Bodenbericht 2003

Kreiner (2003)
Wiener Bodenbericht 2003

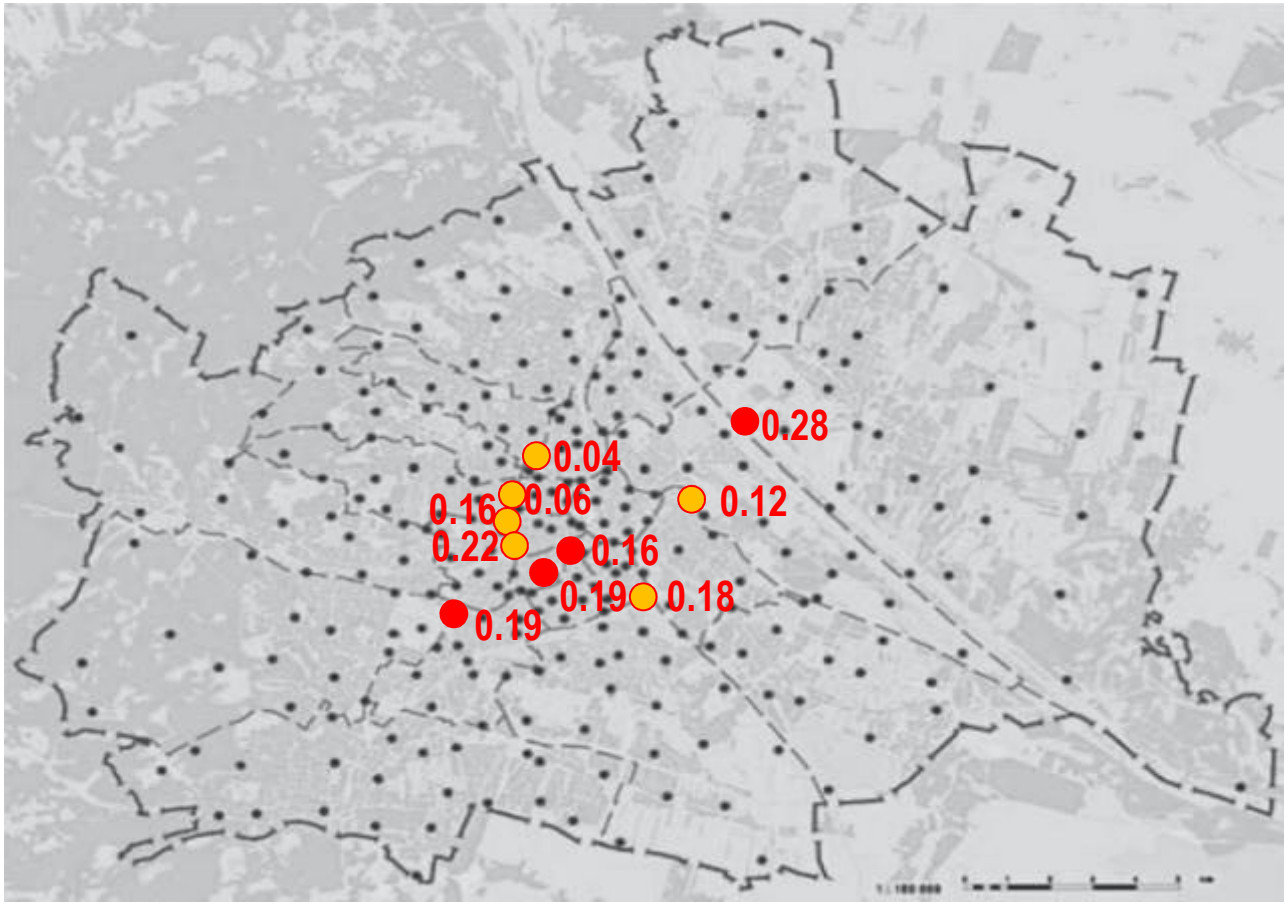


Metals & Metalloids

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Platinum in urban soils (Vienna)

Wiener Bodenberichte 2000 und 2003



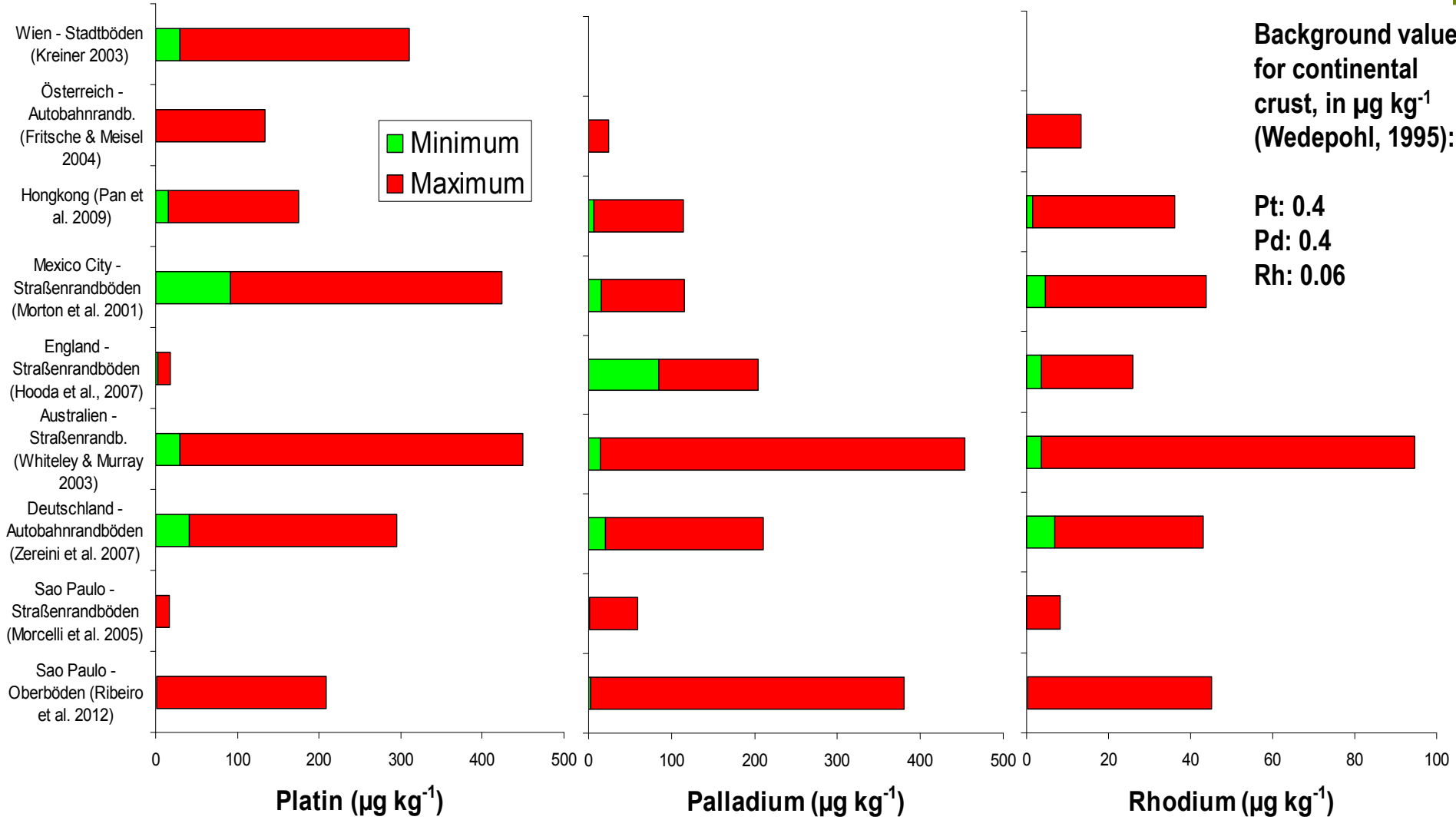
Kreiner (2003)
Wiener Bodenbericht 2003

Kreiner (2000)
Wiener Bodenbericht 2000

- Pt < 0.03 mg kg^{-1}
- Sampling 2000
- Sampling 2003

Metalls & Metalloids

Platinum group elements in polluted topsoils



Background values for continental crust, in µg kg^{-1} (Wedepohl, 1995):

Pt: 0.4
Pd: 0.4
Rh: 0.06

Metalls & Metalloids

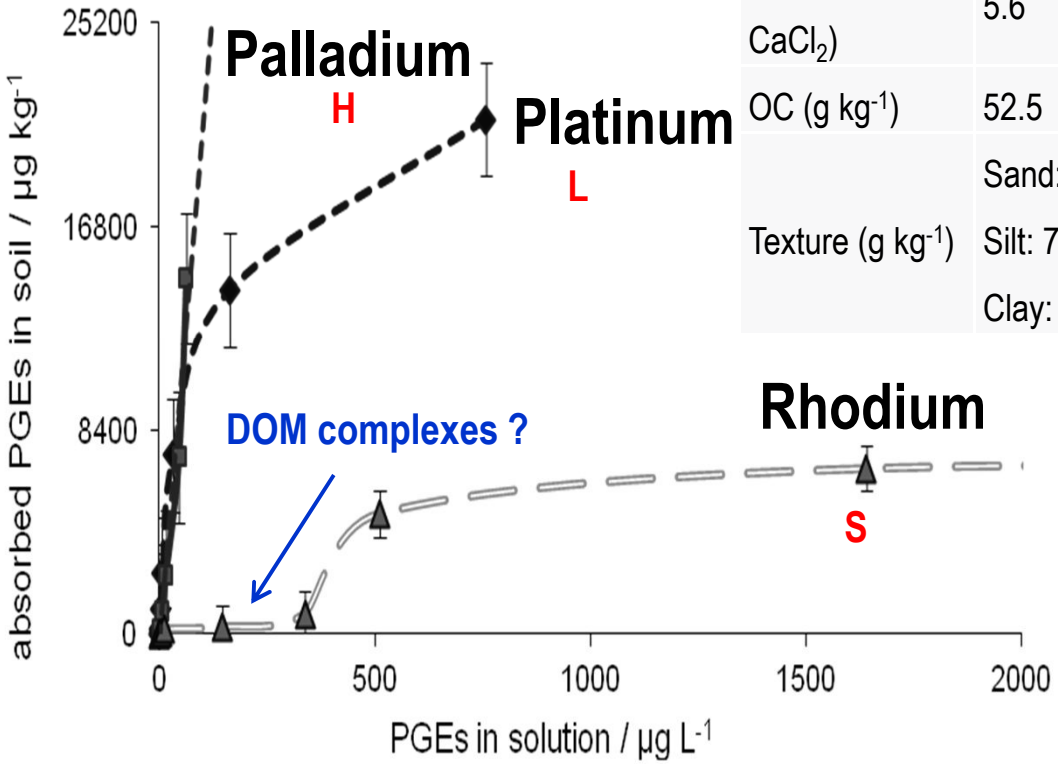
J. Anal. At. Spect
28, 354

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

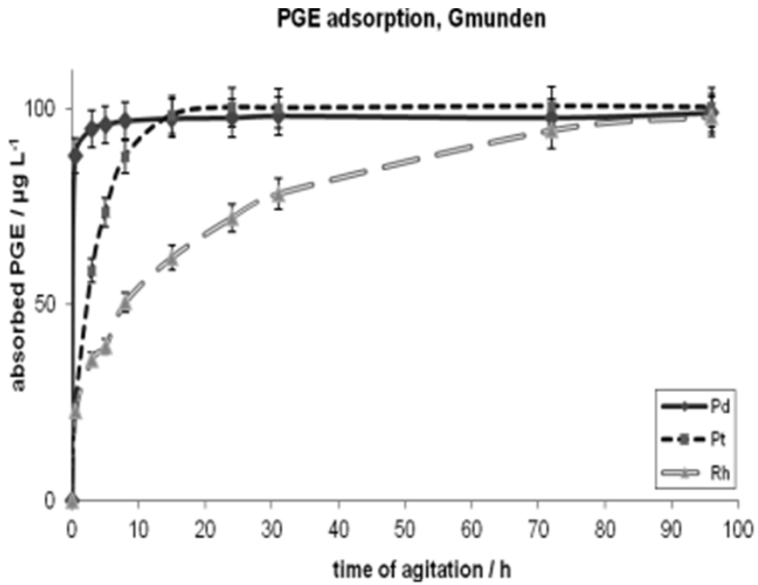
Platinum group elements (Pt, Pd, Rh) – soil

Sorption, Cambisol from Gmunden

pH (H_2O)	6.3
pH (0.01M $CaCl_2$)	5.6
OC (g kg^{-1})	52.5
Texture (g kg^{-1})	Sand: 275 Silt: 725 Clay: 0



Herincs et al. (2013)
J. Anal. Atom. Spectr. 28:354-363.



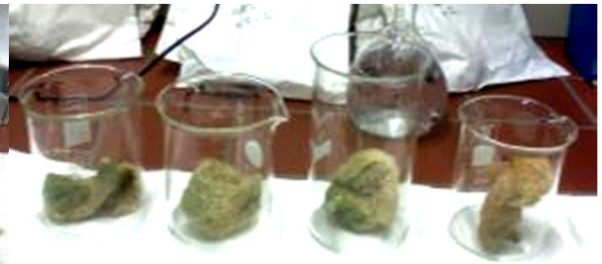
Metalle & Metalloide

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Platinum group elements (Pt, Pd, Rh) - ecotoxicity

Hydroponic experiment with canola (*Brassica napus* L. cv. California)

Hernincs et al. (2013)
In preparation



FWF Project P 20838 N17

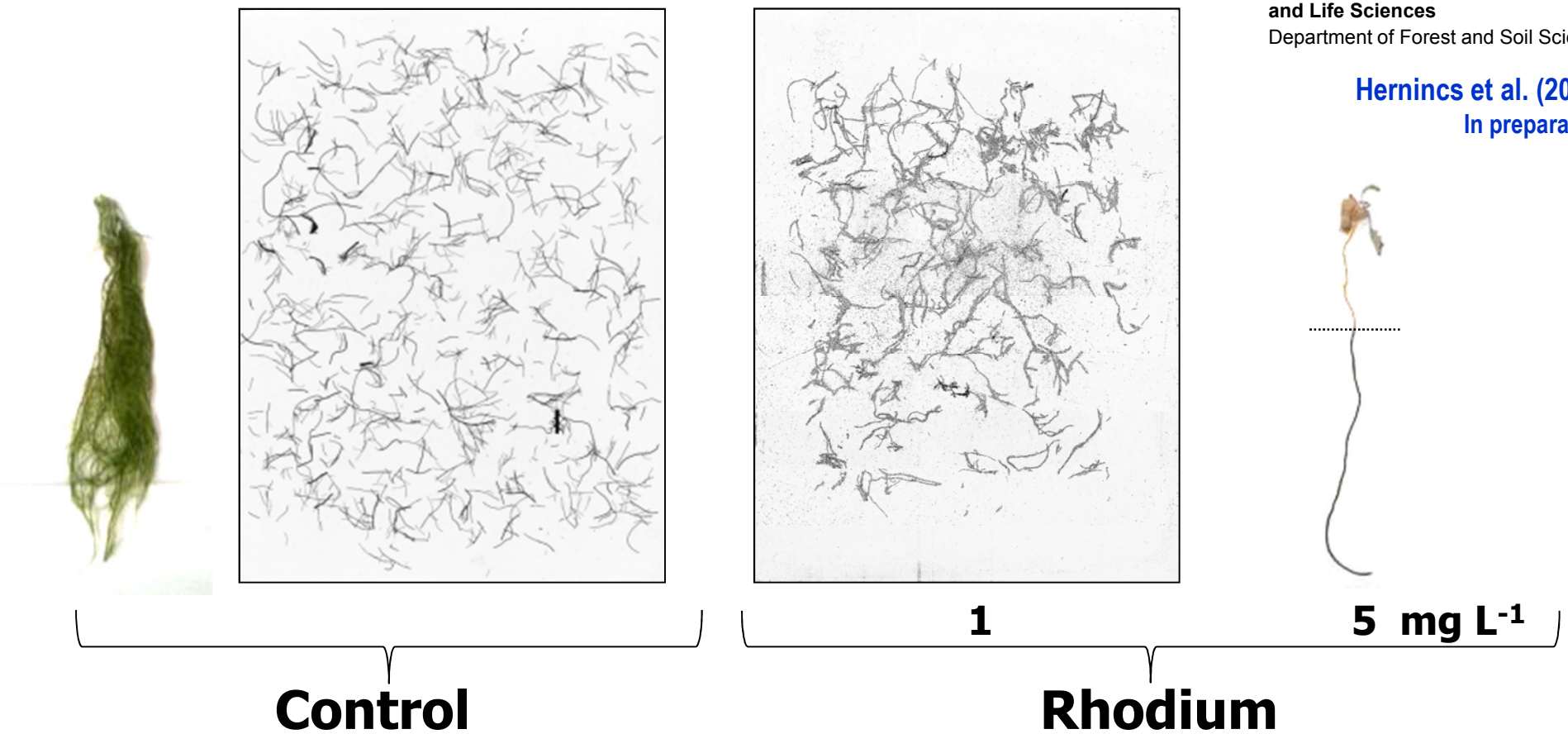
Metalls & Metalloids

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Platinum group elements (Pt, Pd, Rh) - ecotoxicity

Rhodium negatively affects root development at bei pH=7

Hernincs et al. (2013)
In preparation



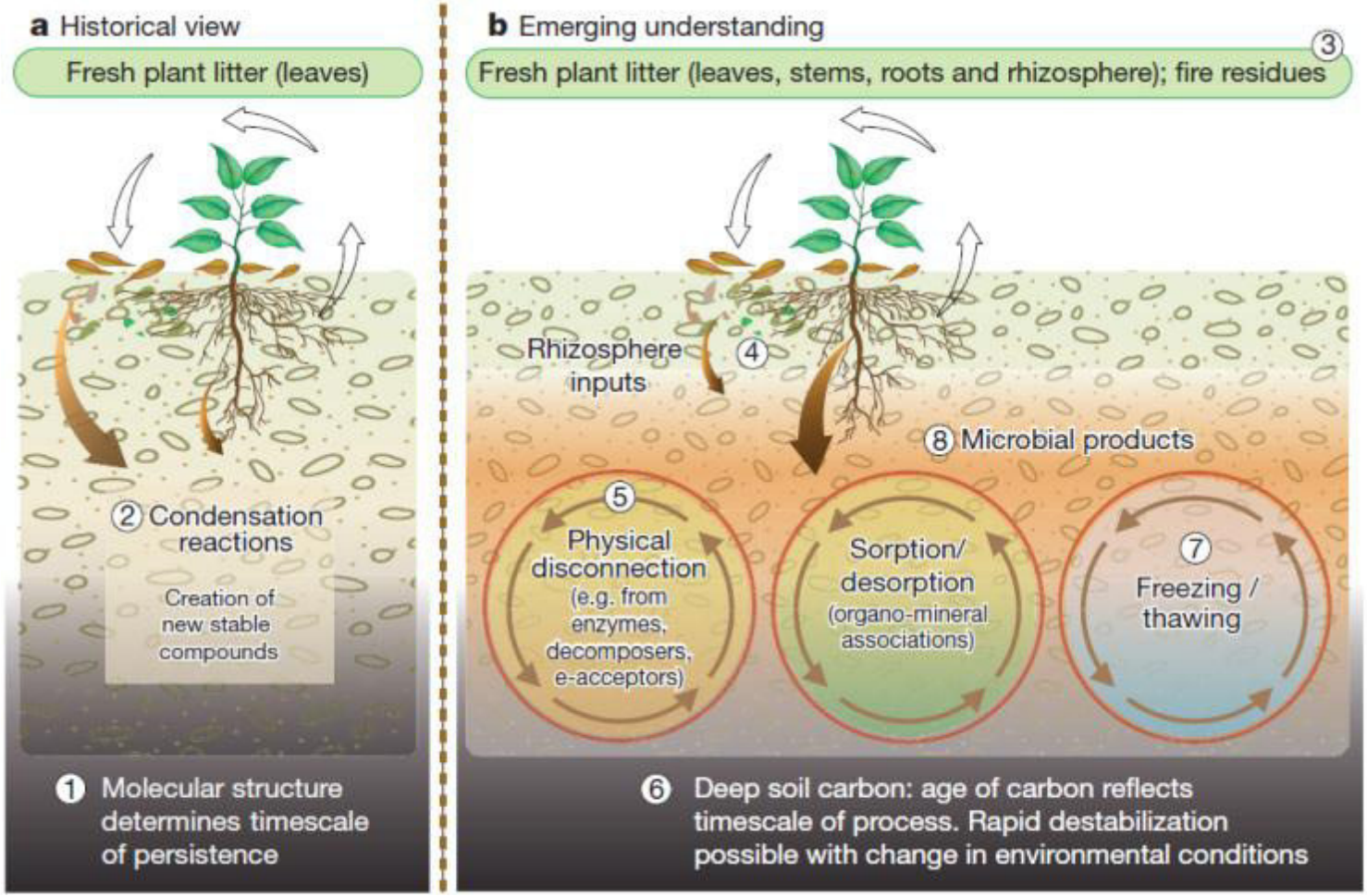
Carbon Sequestration

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Historical concepts and emerging understanding of carbon sequestration in soils

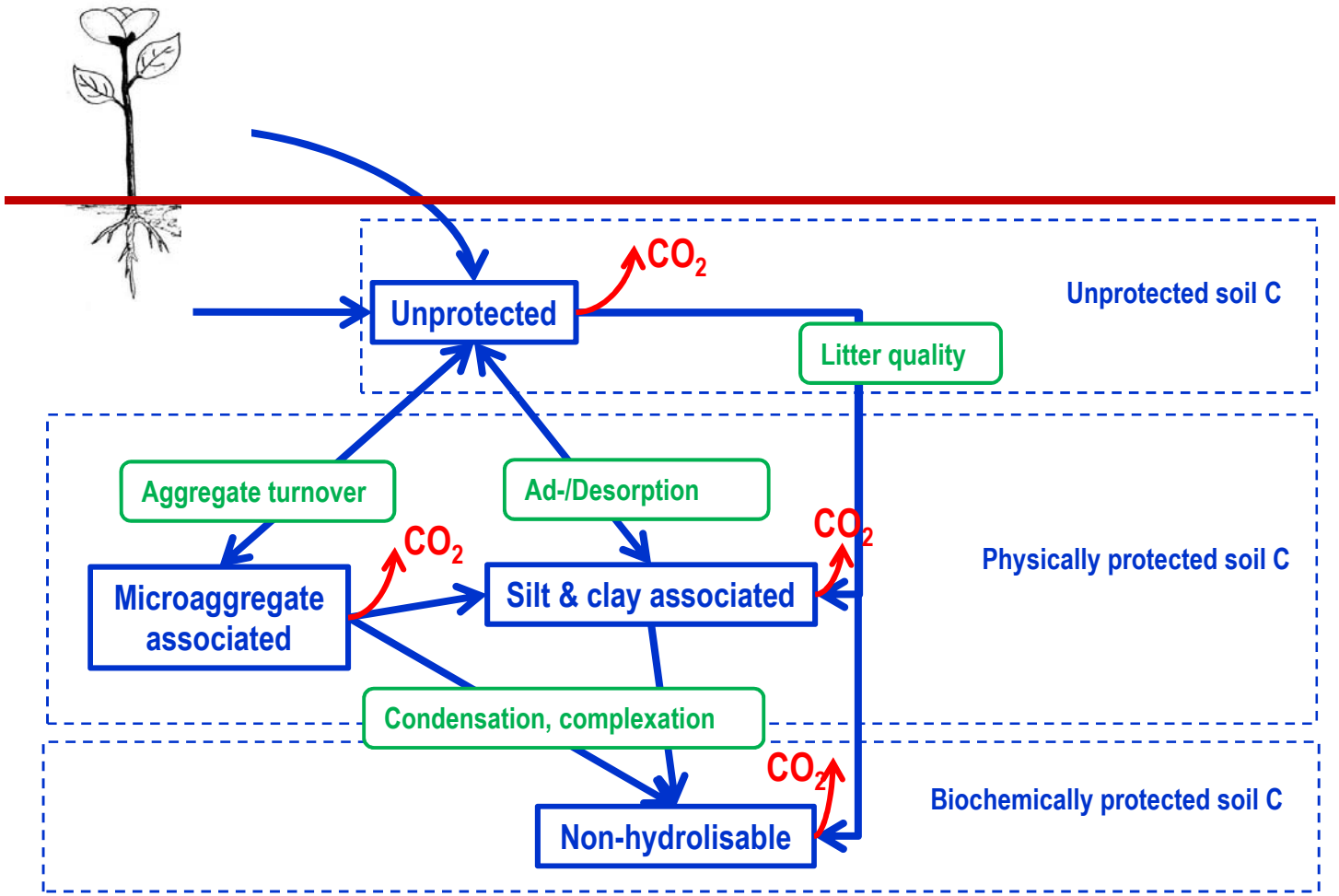
Increased importance of texture, structure, rhizosphere, subsoil...

Schmidt et al. (2010)
Nature 478: 49-56.



Carbon Sequestration

Model of carbon stability in soil



ca. 85% of total C

Angers et al. (2011)
Soil Use & Management 27: 448-452.

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

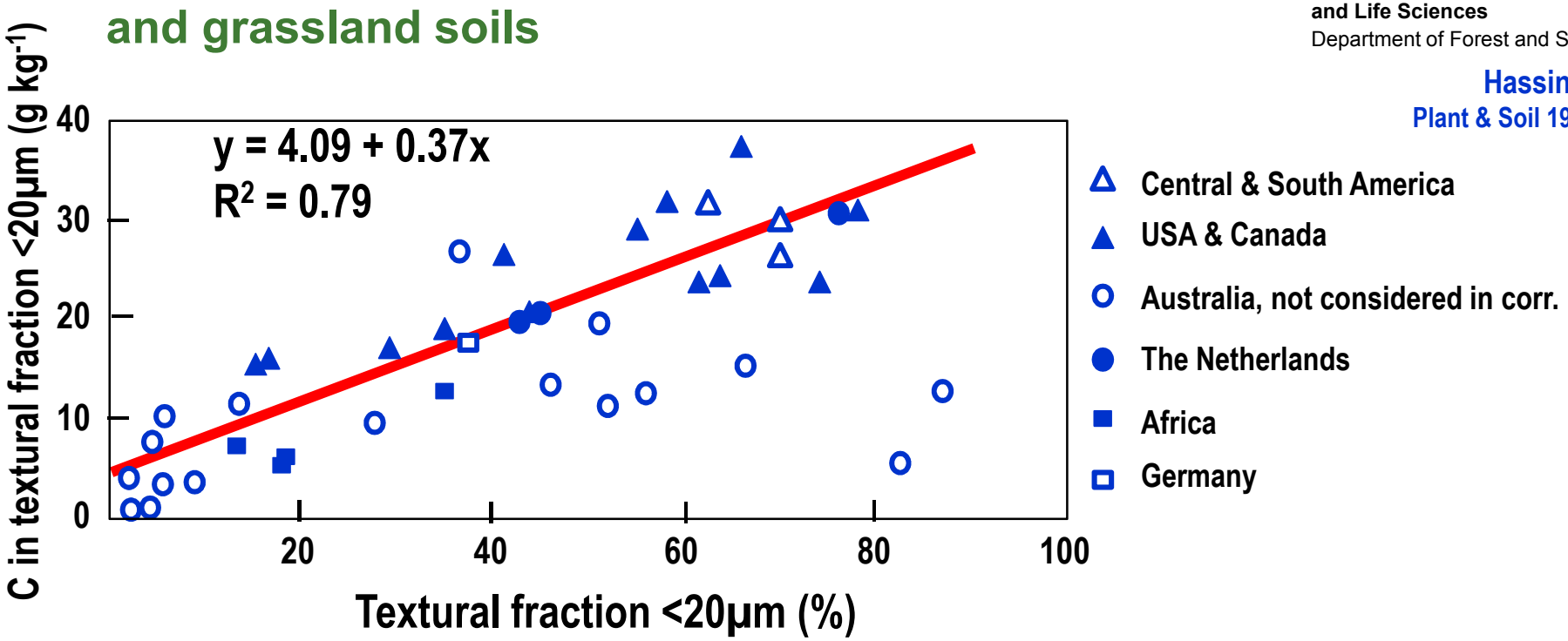
Six et al. (2002)
Plant & Soil 241: 155-176.

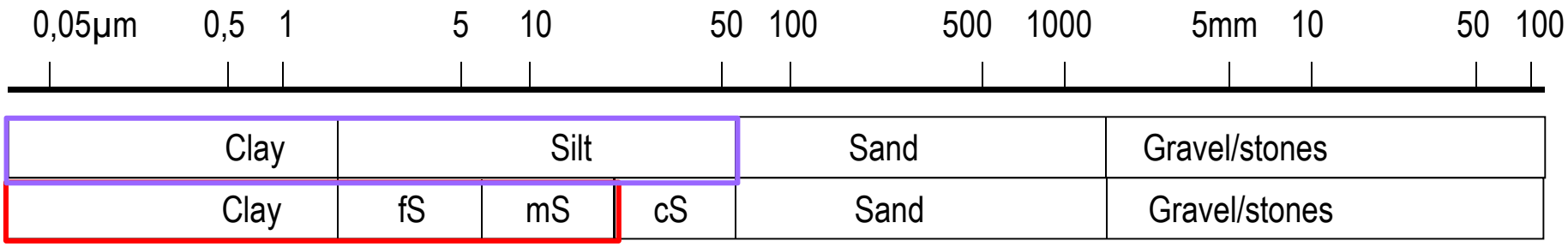
Carbon Sequestration

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Correlation between textural fraction <20µm (=T, fU+mU) carbon bound to this fraction in uncultivated and grassland soils

Hassink (1997)
Plant & Soil 191: 77-87.



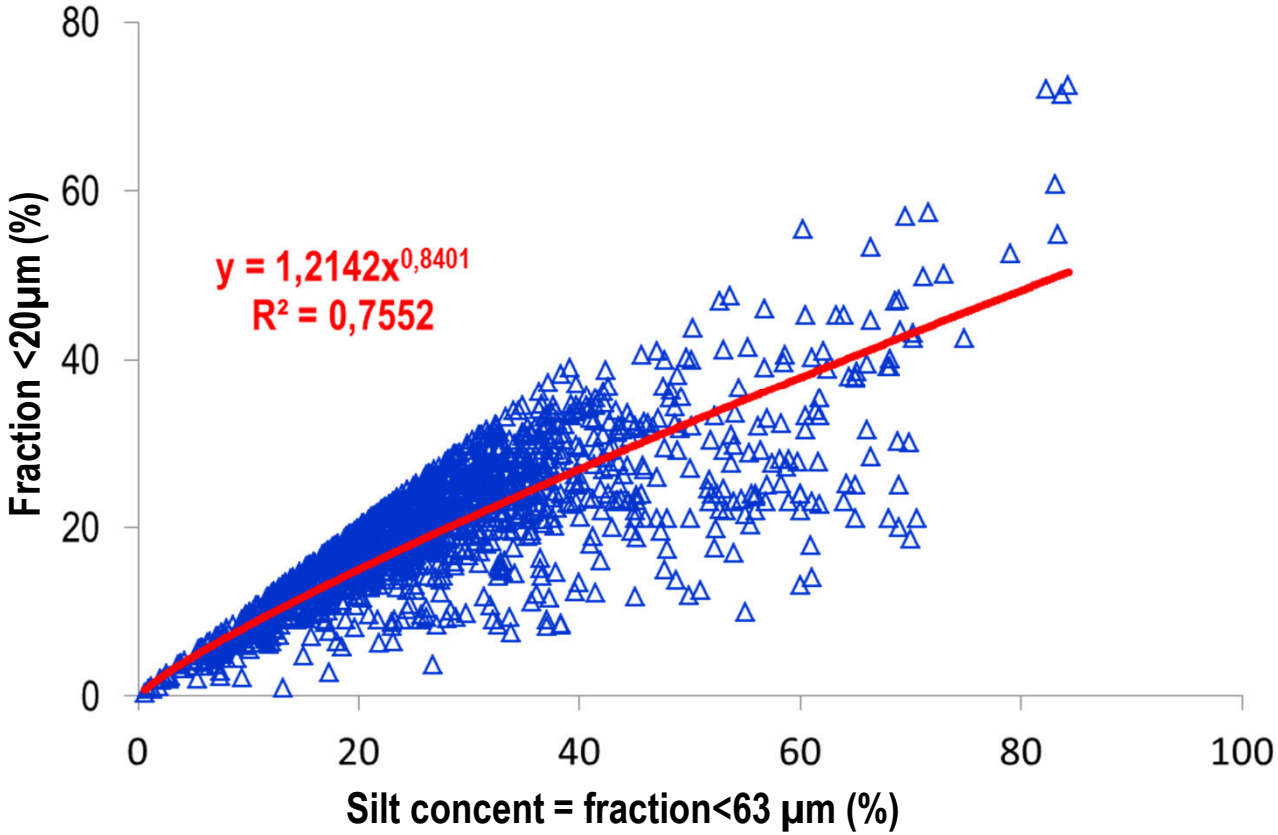


Carbon Sequestration

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Calculation of fraction <20µm from silt content

Data sources: Heft 63 ÖBG, Jandl (1987), BZI Salzburg



Carbon Sequestration

University of Natural Resources
and Life Sciences
artment of Forest and Soil Sciences

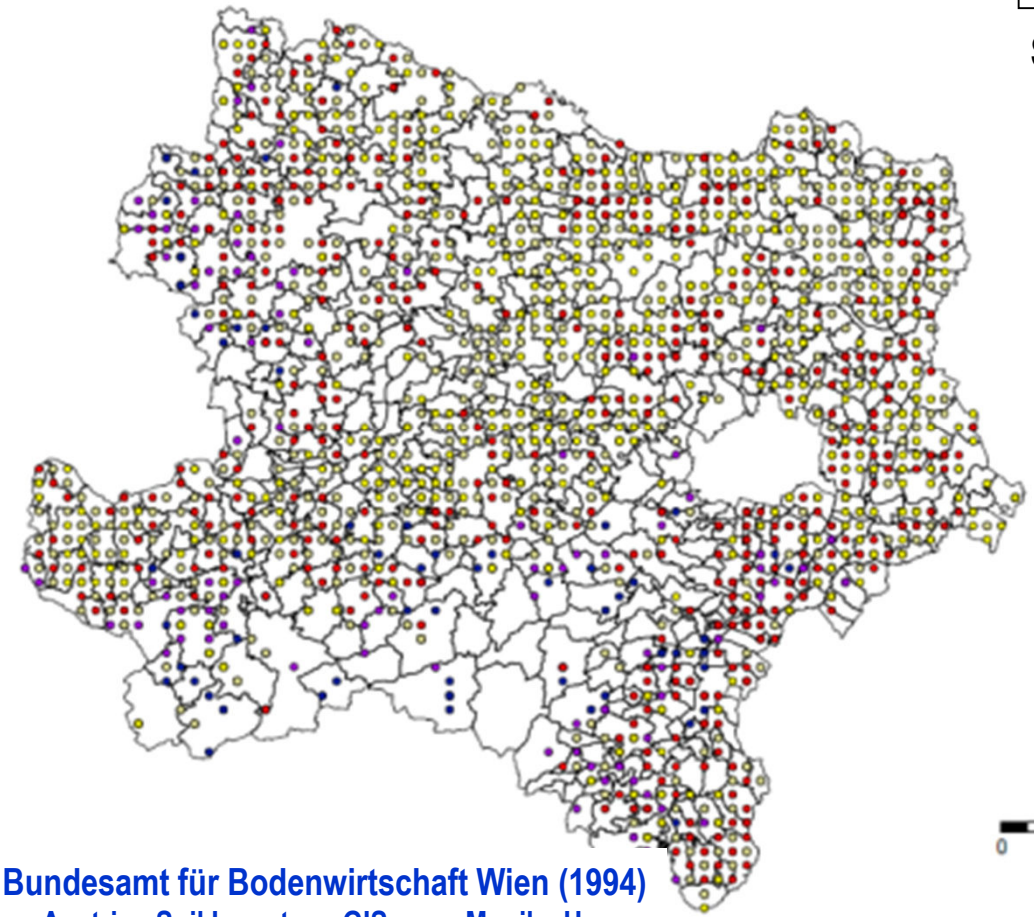
Humus contents in Lower Austrian soils

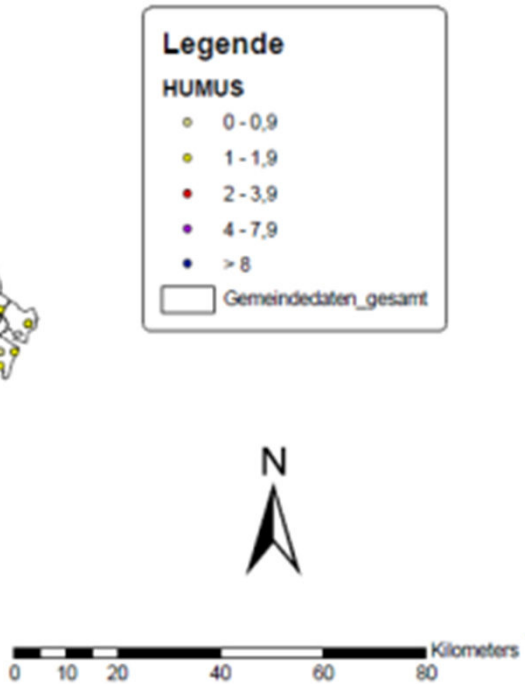
Soil sampling 1990/91 (BZI)

Organic matter % → **x 0.85 = SSOC**

Stable organic carbon

Angers et al. (2011)
Soil Use & Management
27: 448-452.

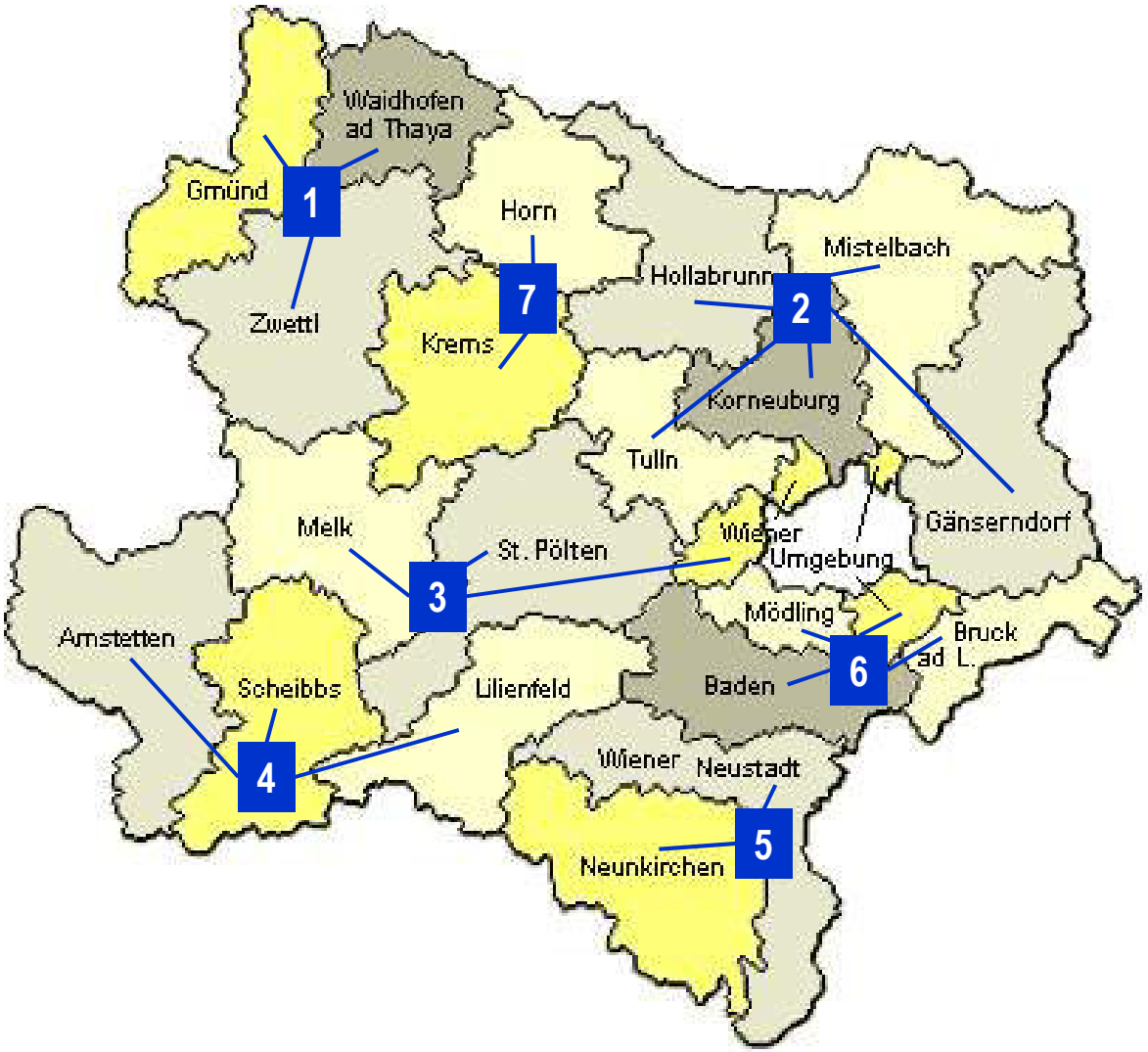




Bundesamt für Bodenwirtschaft Wien (1994)
Lower Austrian Soil Inventory. GIS map: Monika Humer

Carbon Sequestration

Partitioning into regions



University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

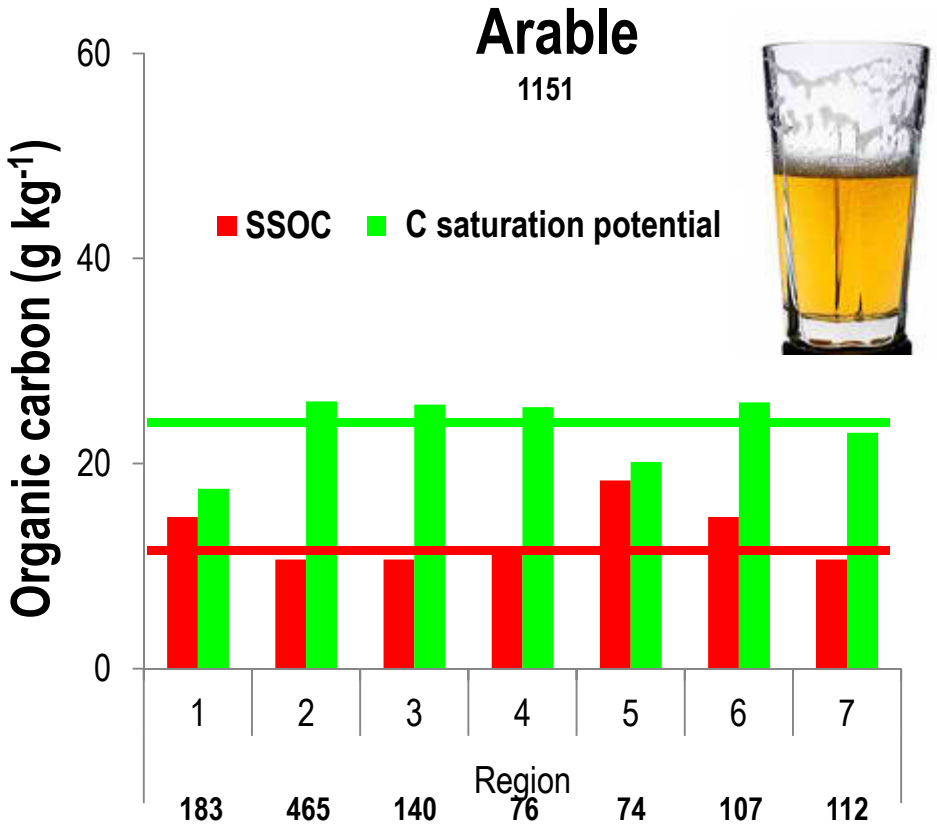
Carbon Sequestration

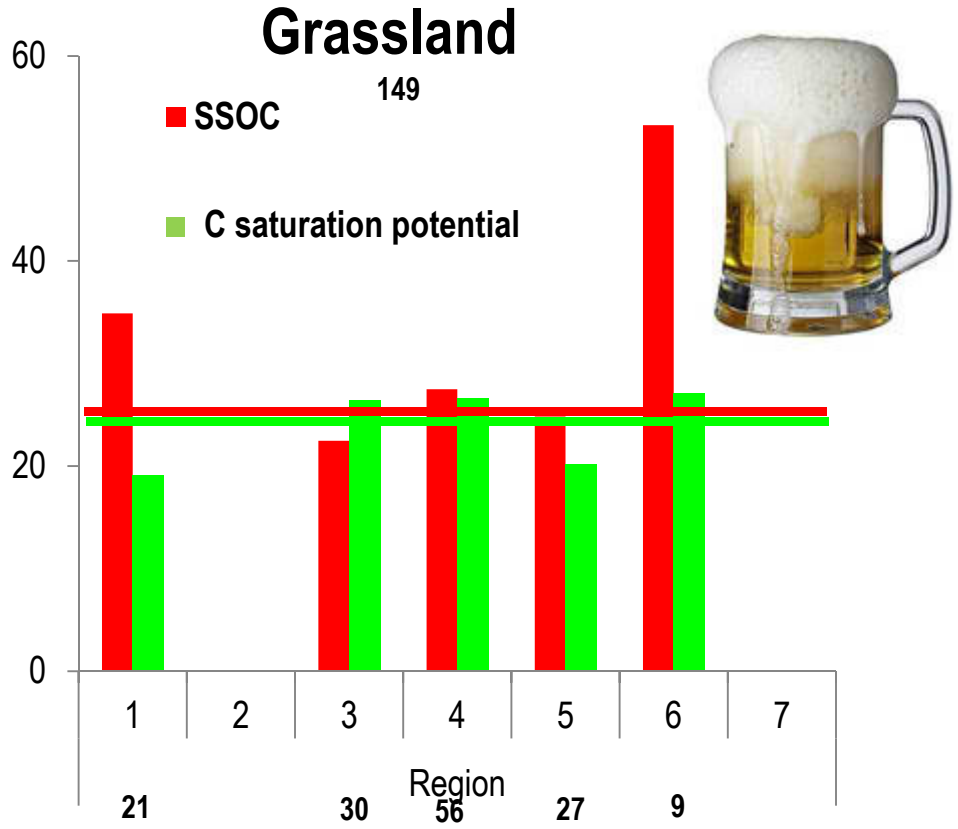
Saturation potentials & stable C in Lower Austrian topsoils

Medians for Lower Austria (lines) und regions (bars); soil depth 0-20 cm

Data source: BZI NÖ (sampling 1990/91)

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences





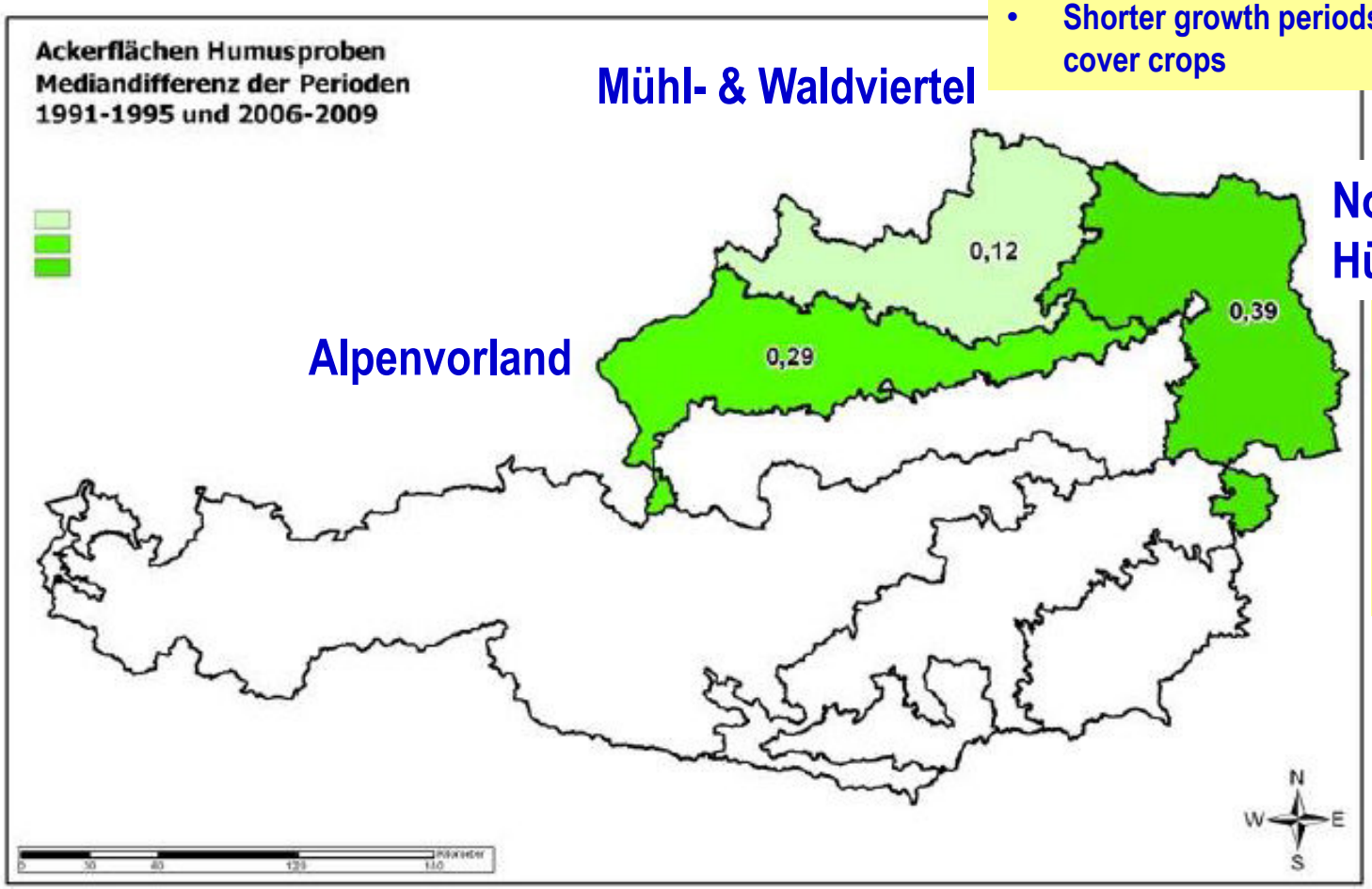
Carbon sequestration

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Increase of C_{org} (Median) in arable soils between 1991/95 and 2006/2009 in three main production areas

AGES (2010)
ÖPUL-Evaluierung.

- Initially higher C saturation
- Shorter growth periods for cover crops



Nordöstliches Flach- & Hügelland & Marchfeld

- Initially larger C saturation deficit owing to intense cropping and lower C input
- Effect of mulching (cover crops)

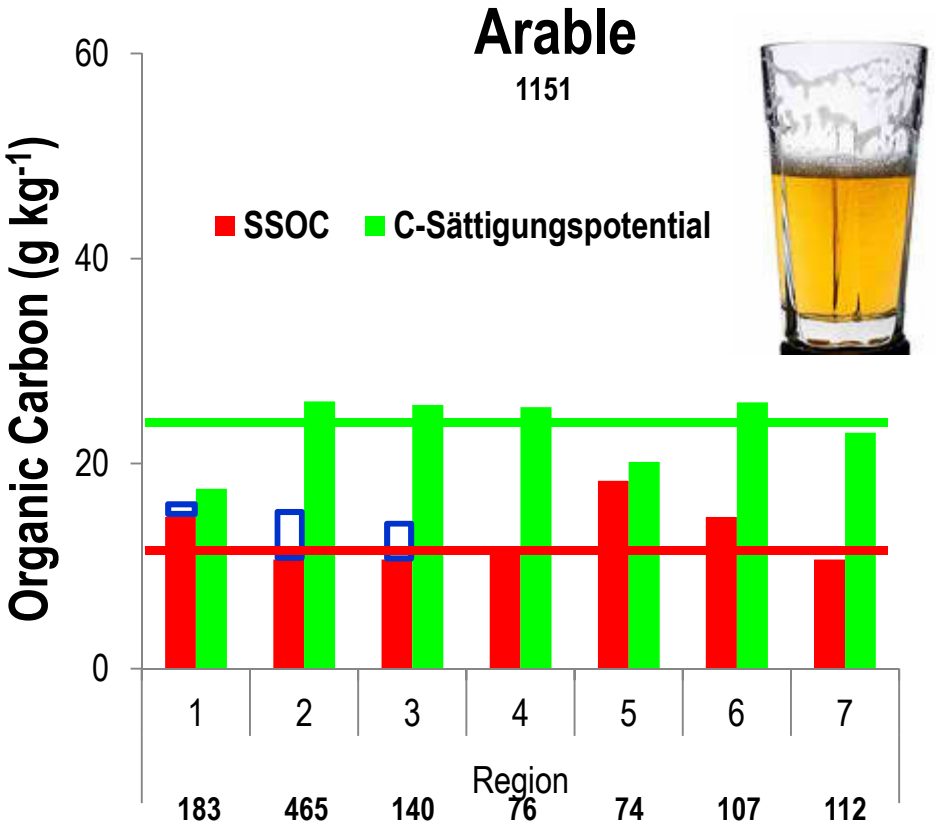
Carbon Sequestration

Saturation potentials and stable C in Lower Austrian arable topsoils

Medians for Lower Austria (lines) and regions (bars); soil depth 0-20 cm

Data source: BZI NÖ (sampling 1990/91)

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences



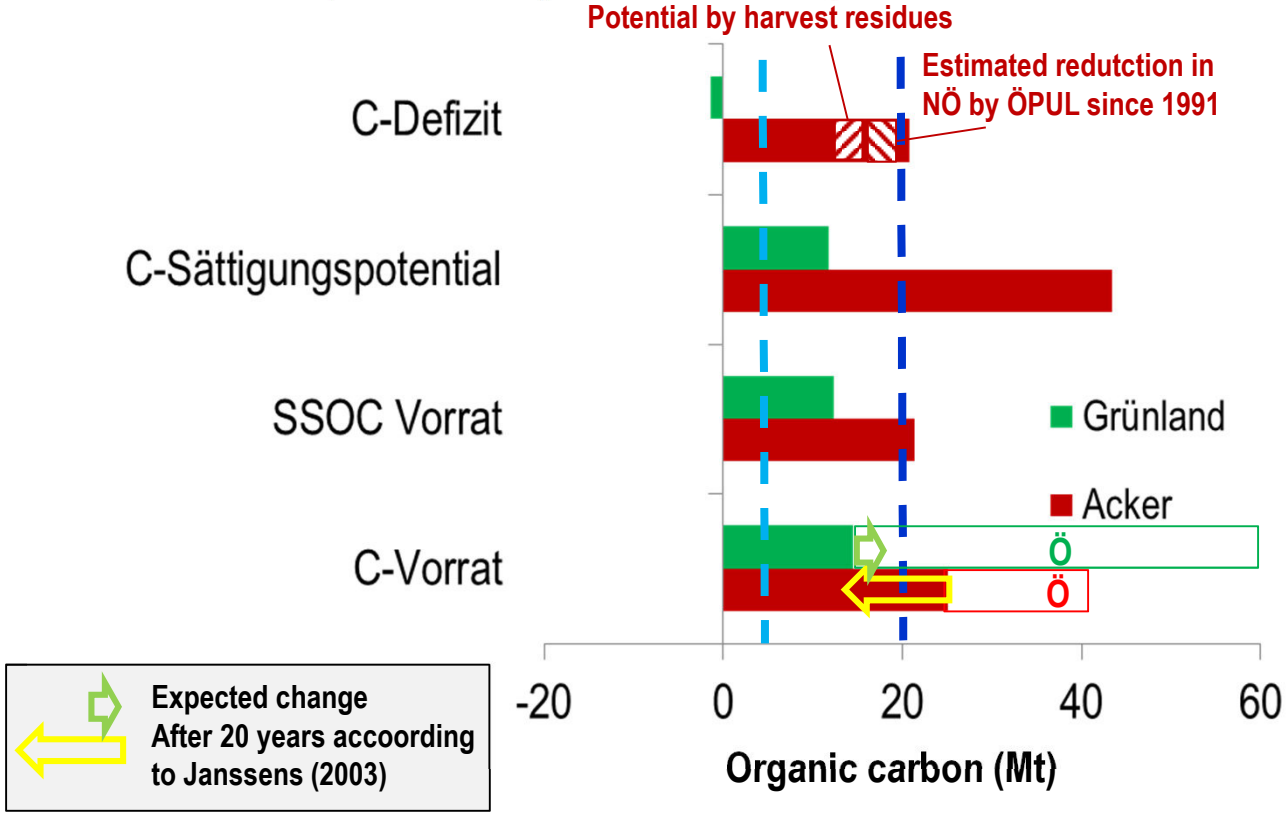
C increase 1991/95-2006/09 (source: AGES, 2010)

Carbon Sequestration

Carbon sequestration potentials in Lower Austrian topsoils under arable and grassland regime

Comparison with anthropogenic C emissions (without LULUCF) & C sequestration by LULUCF 2007 in Austria

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences



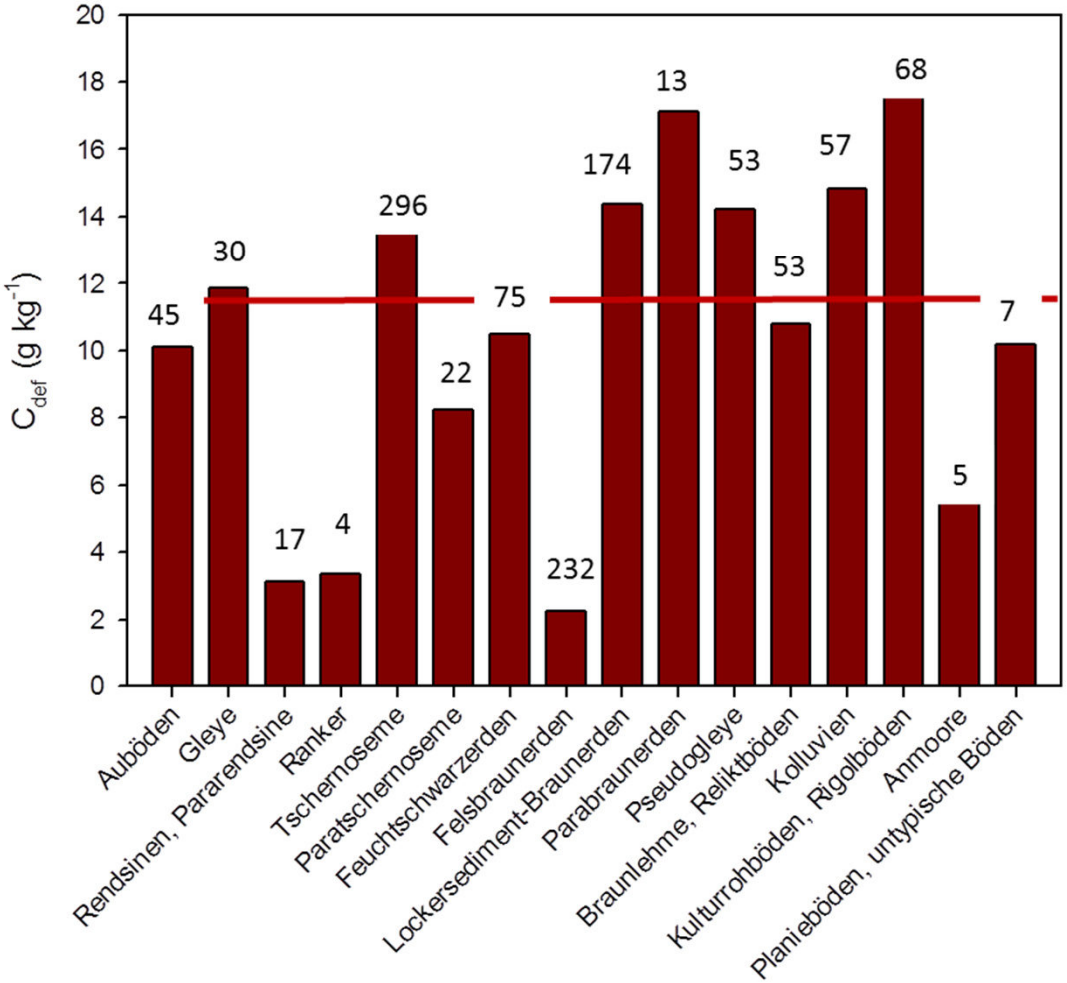
United Nations Framework Convention on Climate Change (2009): National greenhouse gas inventory data for the period 1990-2007.
ÖSTAT (2012): Agrarstrukturerhebung 2010. BZI NÖ
Gerzabek et al. (2005), Canad. J. Soil Sci. 85: 491-498.

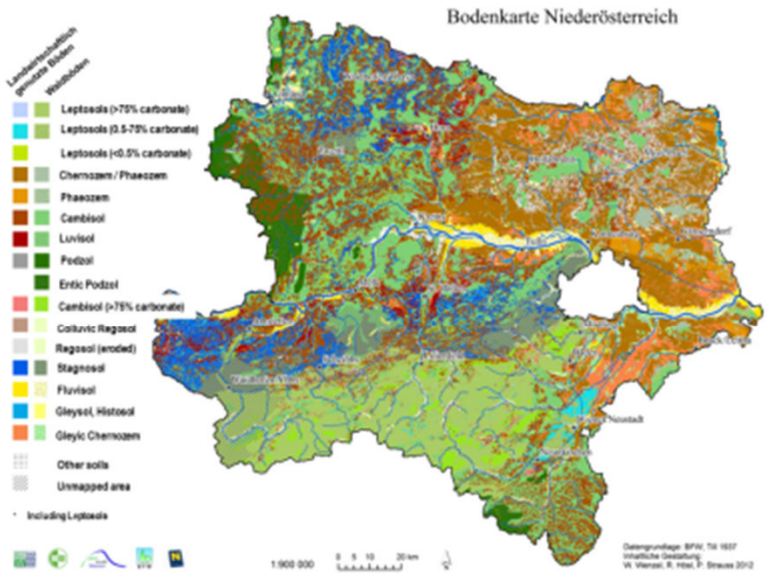
Agrarstrukturerhebung 2010:
Arable land Ö: 1,371.428 ha
Arable land NÖ: 692.121 ha
(ca. 50%)

C losses from arable soils in Lower Austria by soil erosion in 20 years: ca. 1-1.5 Mt

Carbon Sequestration

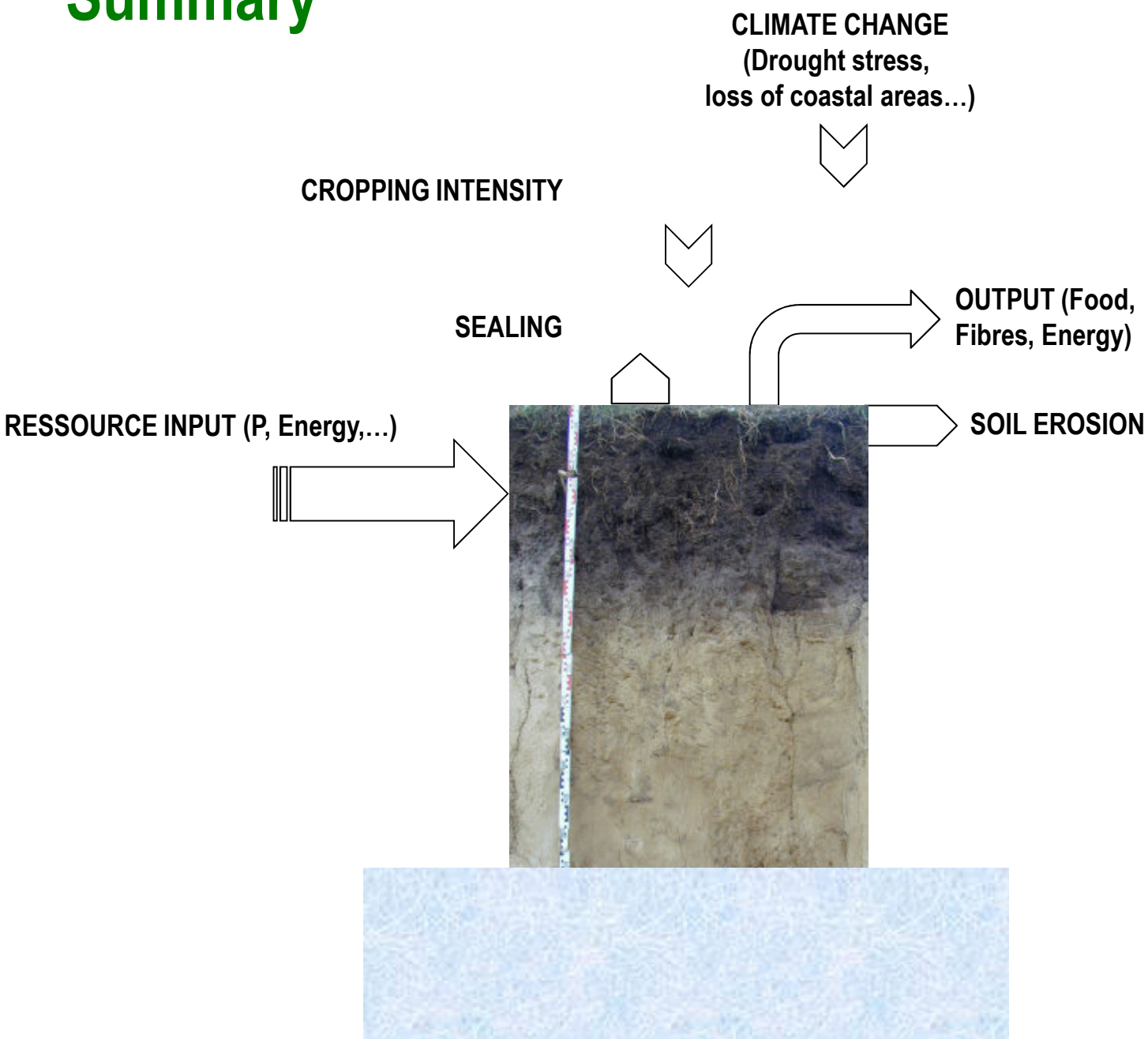
Saturation deficit in various soil types





University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

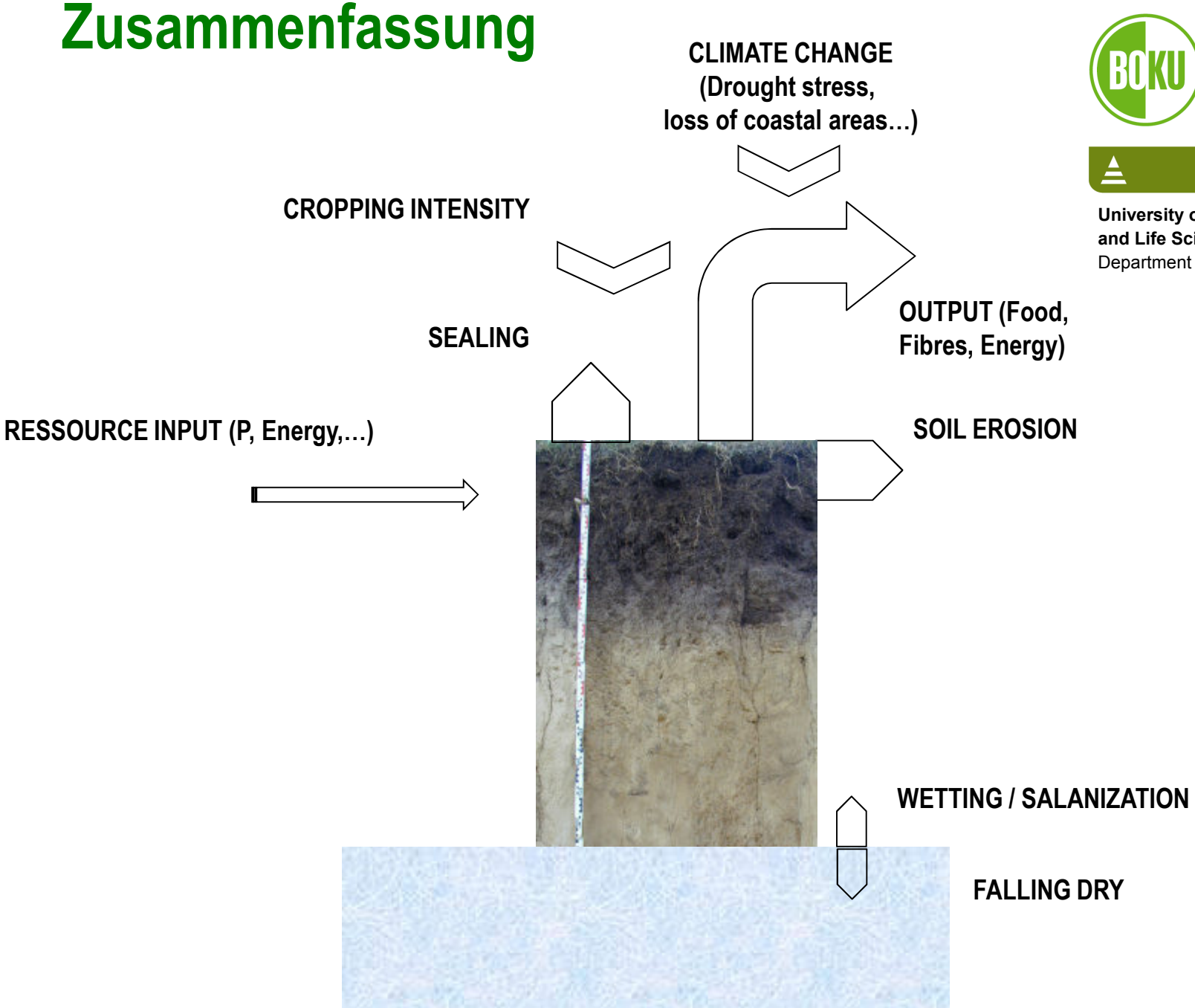
Summary



University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Zusammenfassung

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences



THANK YOU !

Management of Contaminated Soils

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

“Super Fund Sites” (Altlastenstandorte)

Management of Contaminated Soils

Polluted sites in Europe

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

European Environment Agency (2000)

Country	Altlasten	Suspected sites	Costs (Mill. €)	Kommentar zu Kosten
Austria	1.500	80.000	1.500	300 priority areas
Germany	n.n.	240.000	5.200	
Belgium	8.020	14.000	6.900	Total costs
Italy	1.250	8.870	510	1250 priority areas
The Netherlands	n.n.	115.000	up to 46.000	Total costs
France	9000	175.000	n.n.	-
Denmark	14.000	40.000	1.138	Total costs

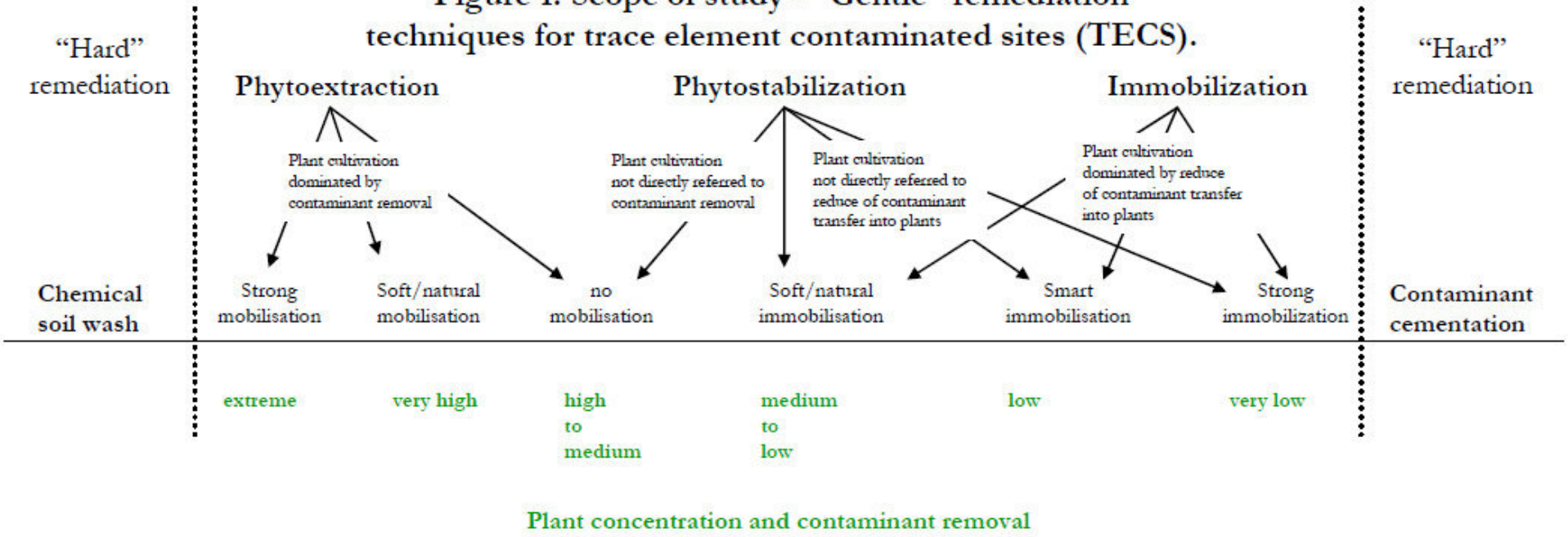
Management of Contaminated Soils

Gentle remediation technologies

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Puschenreiter et al. (2008):
SUMATECS. Final Research Report.

Figure 1: Scope of study - "Gentle" remediation techniques for trace element contaminated sites (TECS).

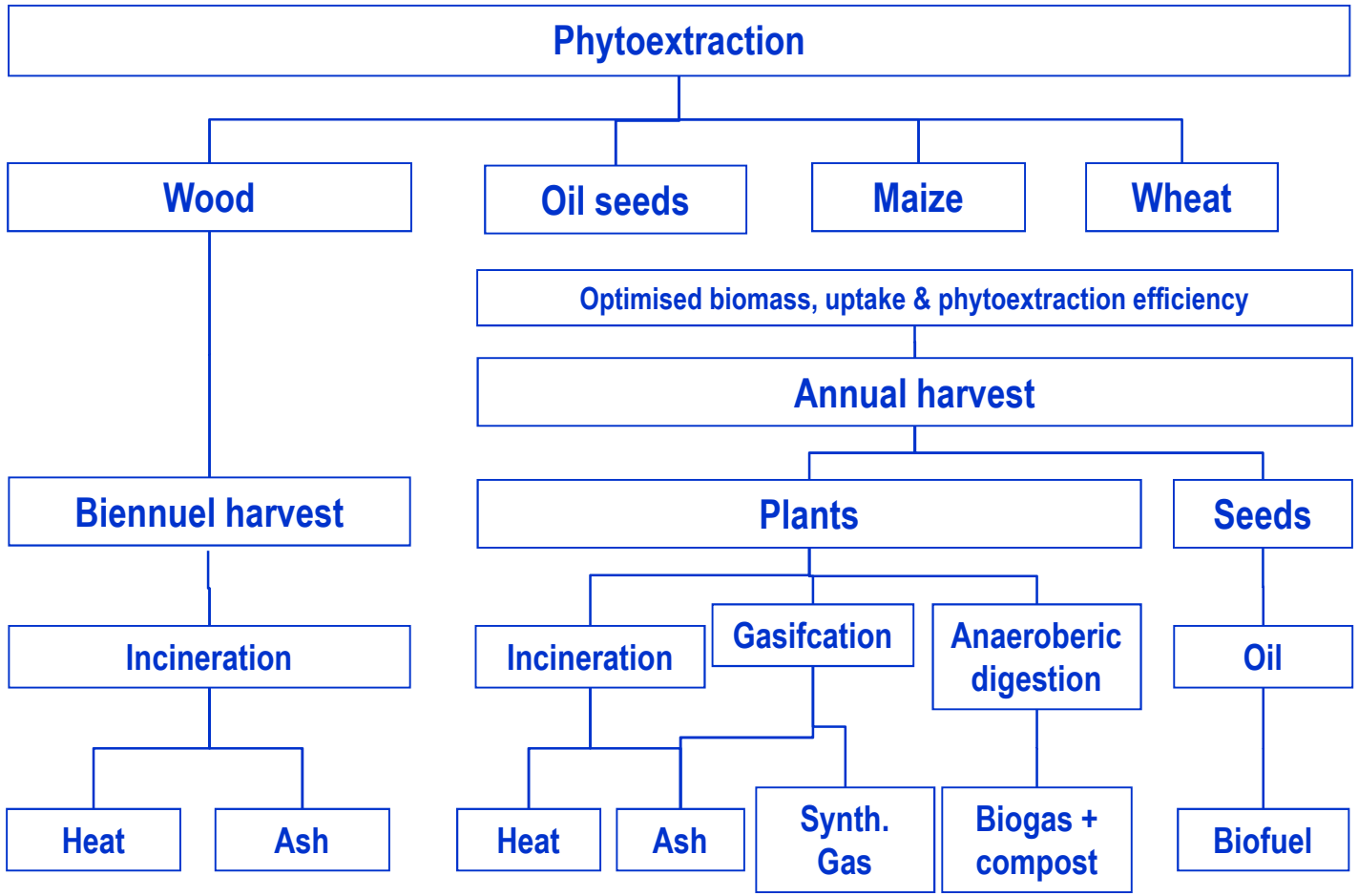


Management of Contaminated Sites

Options for energetic use of phytoremediation crops

University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Puschenreiter et al. (2008):
SUMATECS. Final Research Report.



Management of Contaminated Soils

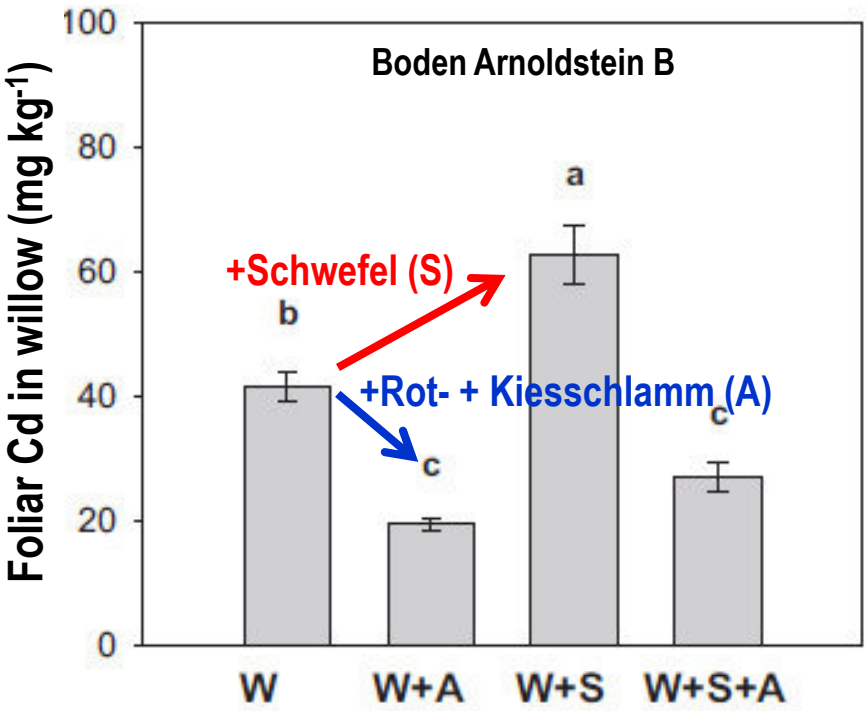
University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Soil management using mobilising (sulfur) und immobilisating (red mud & gravel sludge) soil additives

- Contaminated soil (Pribram), willow (*Salix smithiana*)

  Extraction of about 2% of total soil Cd after 160 days
  Enhanced to 3% upon elemental sulfur application

Iqbal et al. (2012)
Environmental Pollution 170: 222-231



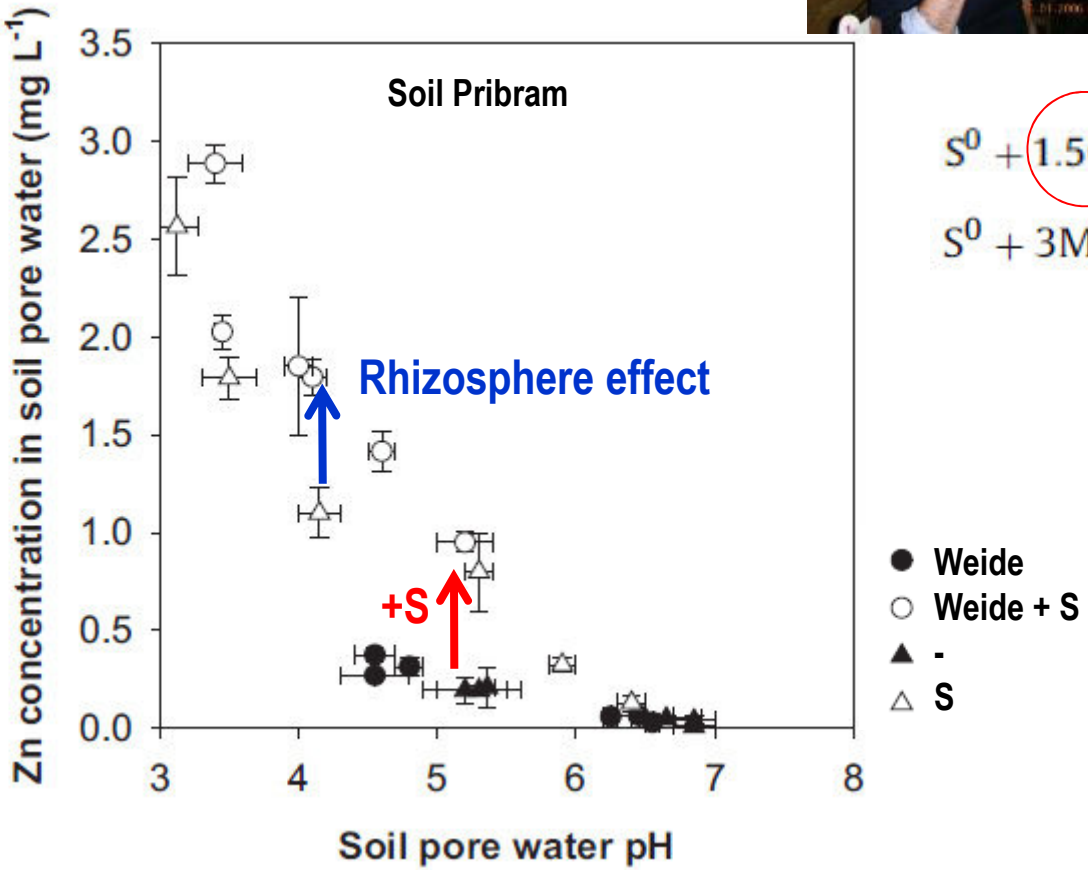
Management of Contaminated Soils

Soil management by elemental sulfur addition

- Rhizosphere effect

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Iqbal et al. (2012)
Environmental Pollution 170: 222-231



$$S^0 + 1.5O_2 + H_2O \rightarrow H_2SO_4$$ ➡ pH ↓ ➡ Cd^{2+}, Zn^{2+}

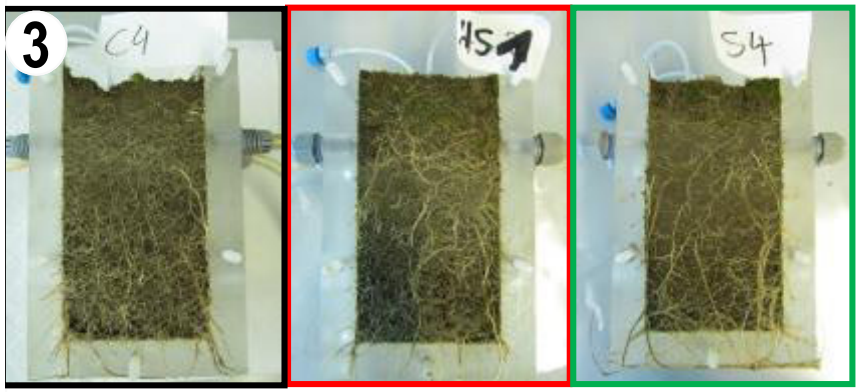
$$S^0 + 3MnO_2 + 2H_2O \rightarrow SO_4^{2-} + 3Mn^{2+} + 4OH^-$$

➡ Cd^{2+}, Zn^{2+} ➡ Uptake in willow

O_2: Planar Optods
Metals: DGT

Management of Contaminated Soils

Soil management by elemental sulfur addition



ity of Natural Resources
e Sciences
nent of Forest and Soil Sciences

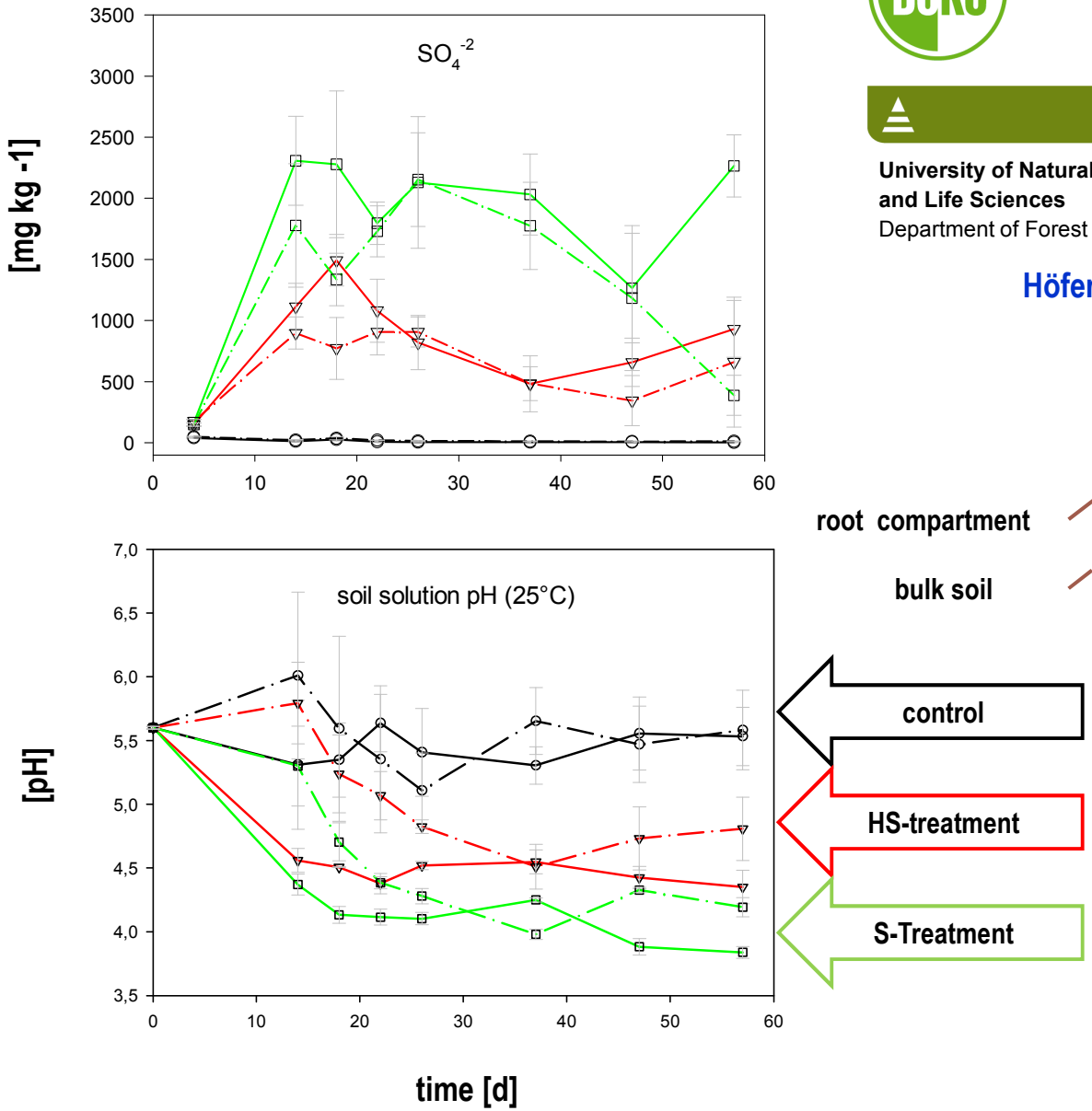
Höfer et al. (2013)
In preparation

(1) start of rhizobox experiment, (2) soil solution sampling procedure during experiment 3mL per compartment, (3) plant compartments after harvest (C4 – Control, HS1 – 0.51g sulphur, S4 – 1.02g sulphur)

Management of Contaminated Soils

Soil management by elemental sulfur addition

- Rhizosphere effect



University of Natural Resources and Life Sciences
Department of Forest and Soil Sciences

Höfer et al. (2013)
In preparation

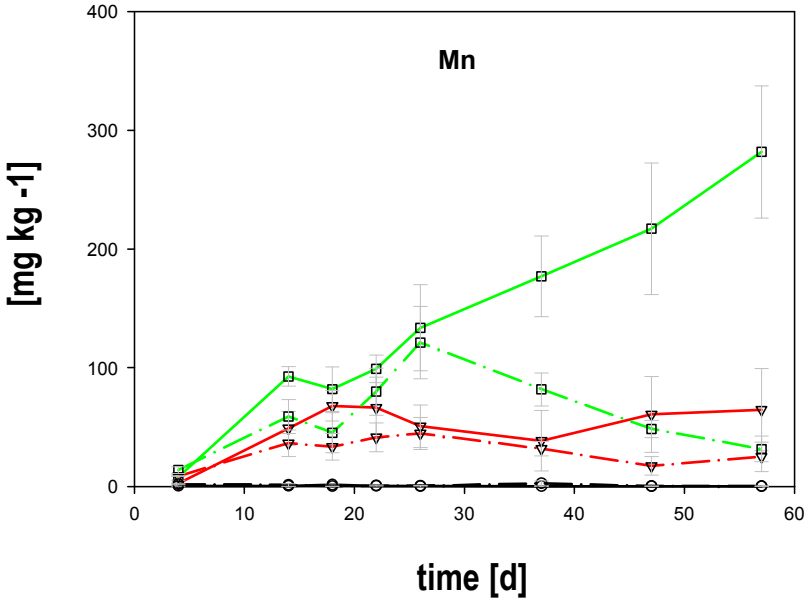
Management of Contaminated Soils

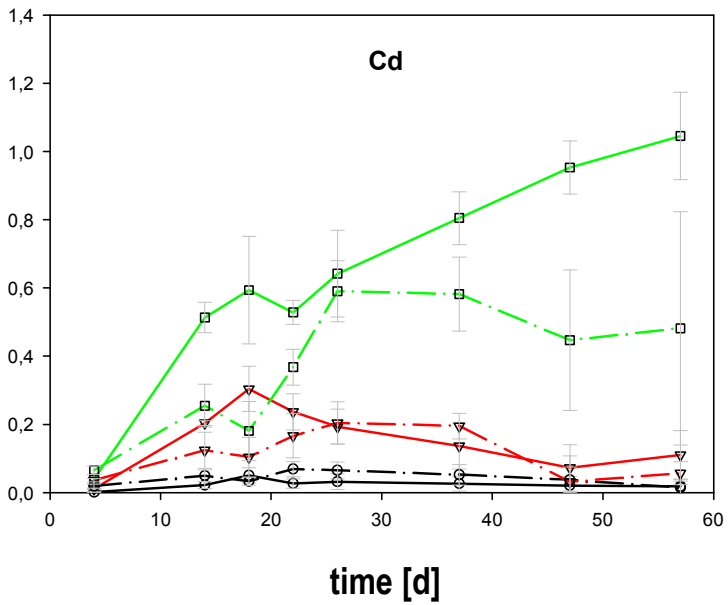
Soil management by elemental sulfur addition

- Rhizosphere effect

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Höfer et al. (2013)
In preparation



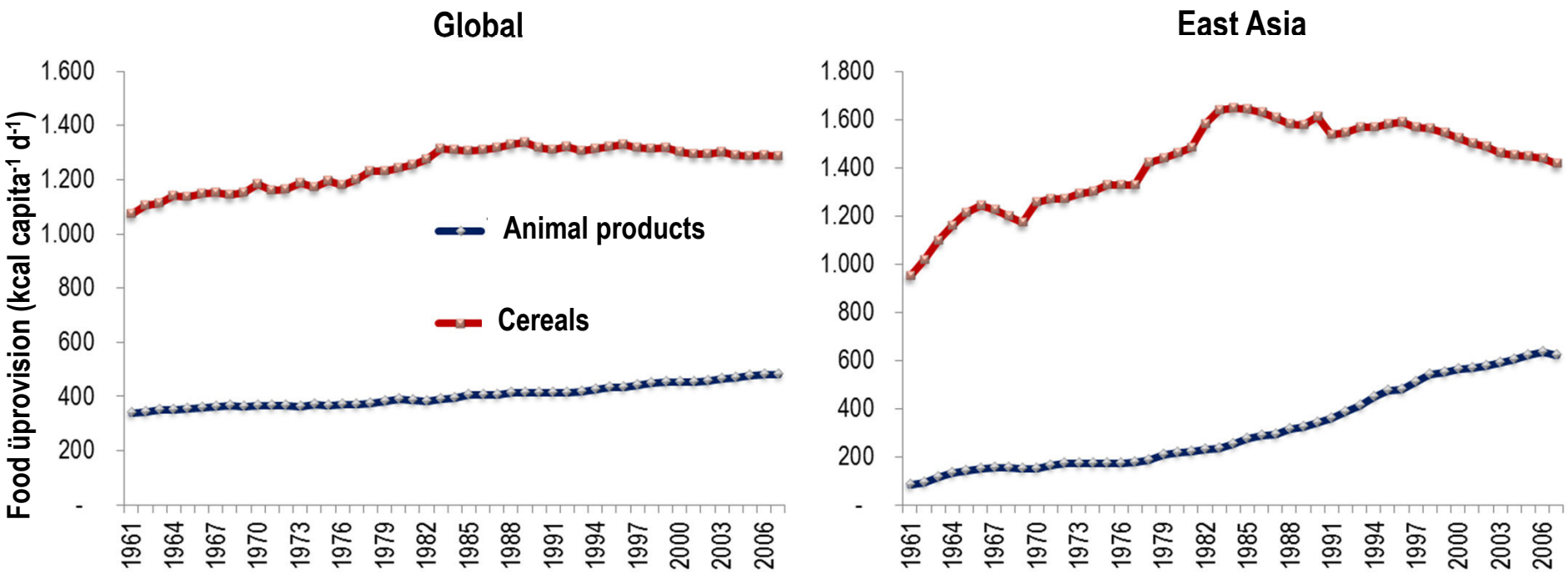


Increasing Land Demand

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Per-capita Provision of Food

Datenquelle: Kastner et al. (2012)
PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1117054109



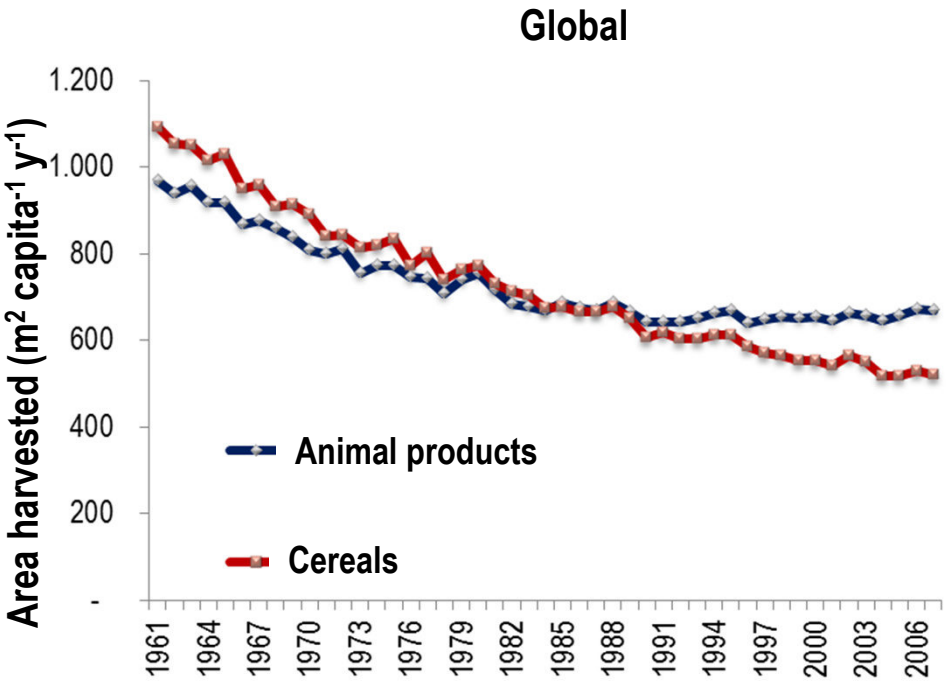
Increasing Land Demand

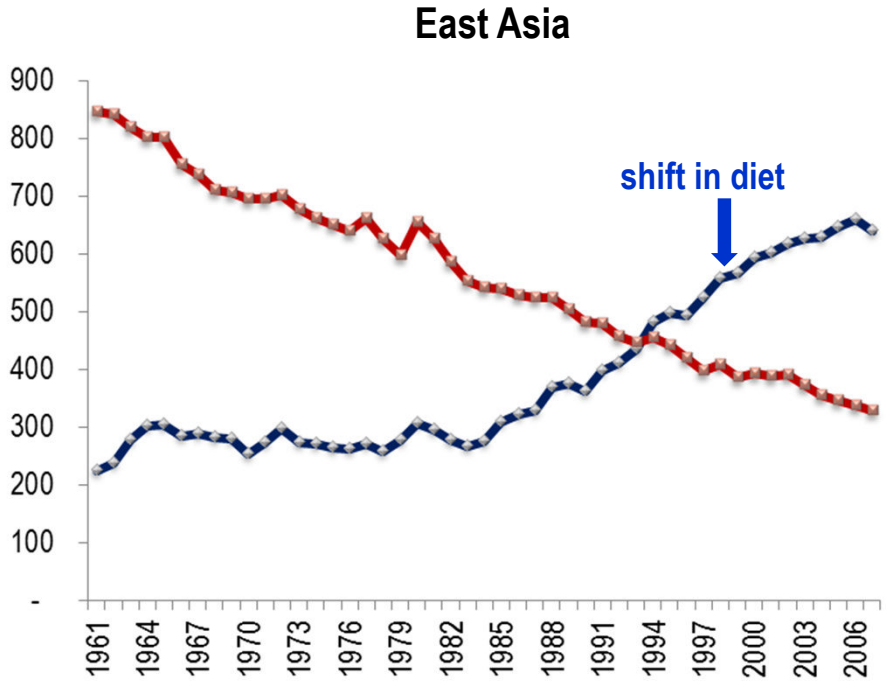
University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences

Pro-capita land requirement for food production

- Progress in land use technology
- Shift in diet towards more meat (emerging economies)

Datenquelle: Kastner et al. (2012)
PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1117054109





Periodic Table of Elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.00794	Atomic # Symbol Name Atomic Mass																2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

C Solid
Hg Liquid
H Gas
Rf Unknown

Metals: Alkali metals, Alkaline earth metals, Lanthanoids, Actinoids, Transition metals, Poor metals
Nonmetals: Other nonmetals, Noble gases

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

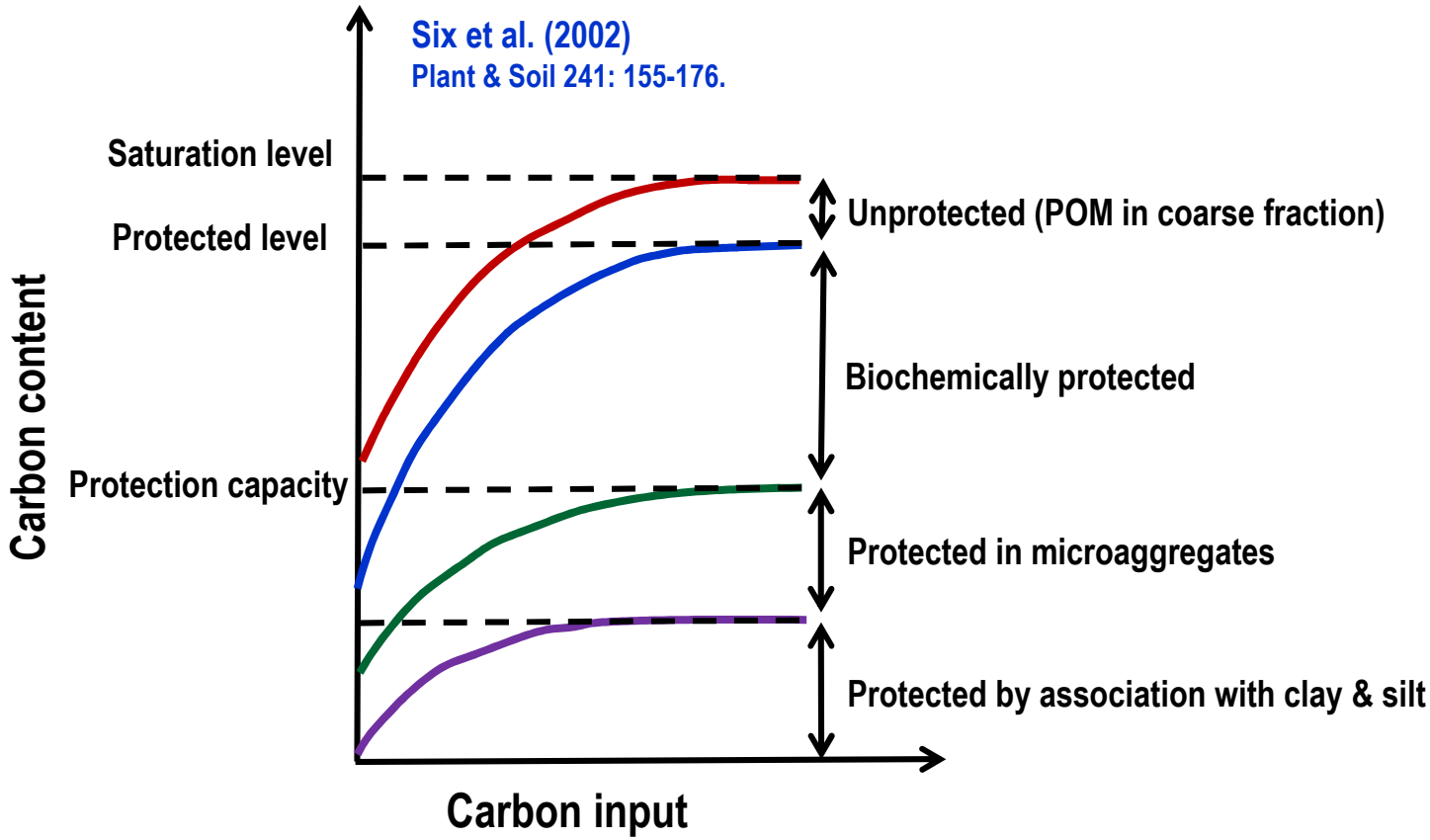
Design and Interface Copyright © 1997 Michael Dayah (michael@dayah.com). http://www.ptable.com/

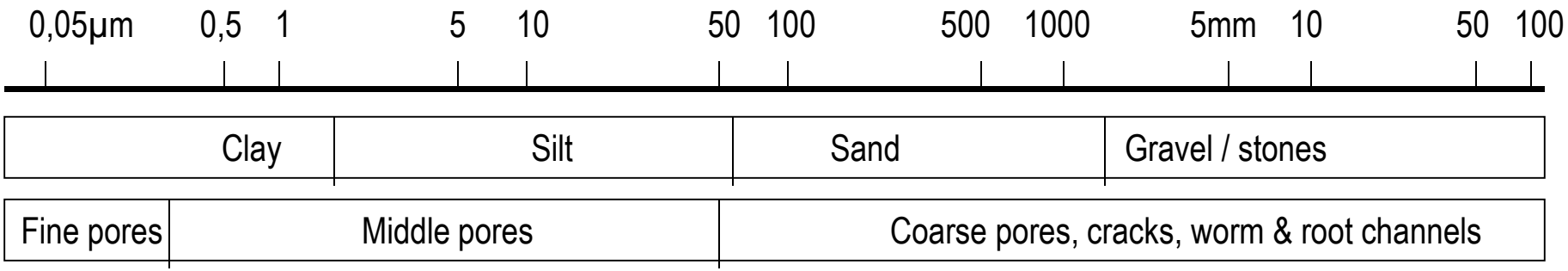
57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Ptable.com

Carbon Sequestration

University of Natural Resources
and Life Sciences
Department of Forest and Soil Sciences



ca. 85% of total C

Angers et al. (2011)
Soil Use & Management
27: 448-452.