Terra Preta – Facts and Myths

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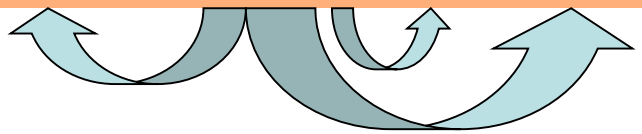
Soil organic matter as management tool

Soil quality = f(AWC, **SOM**, R_d, CEC, clay)$_{time}$



⇒ ***Improved soil fertility***

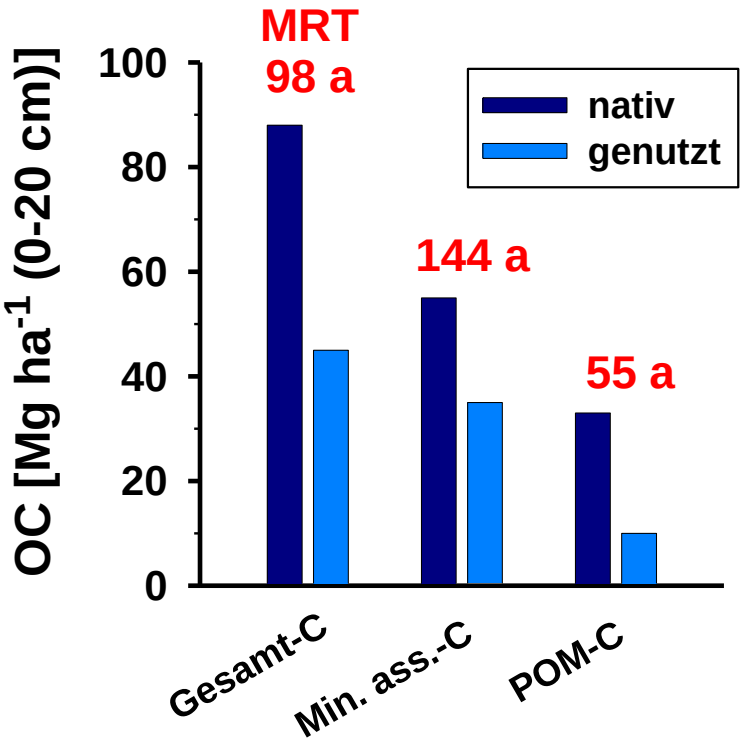
⇒ ***C sequestration***

C sequestration is the transfer of CO_2 from the atmosphere into long-term C pools using biotic and abiotic processes

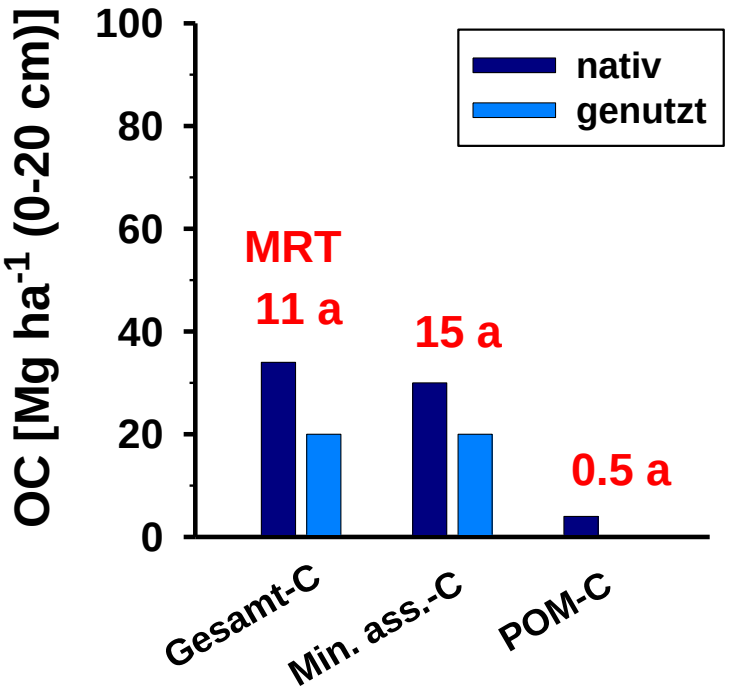
(Lal 1996)

Consequences of continous soil use

Chernozem (Prairie)
65 years of continuous use



Ferralsol (Savanne)
6 years of continuous use

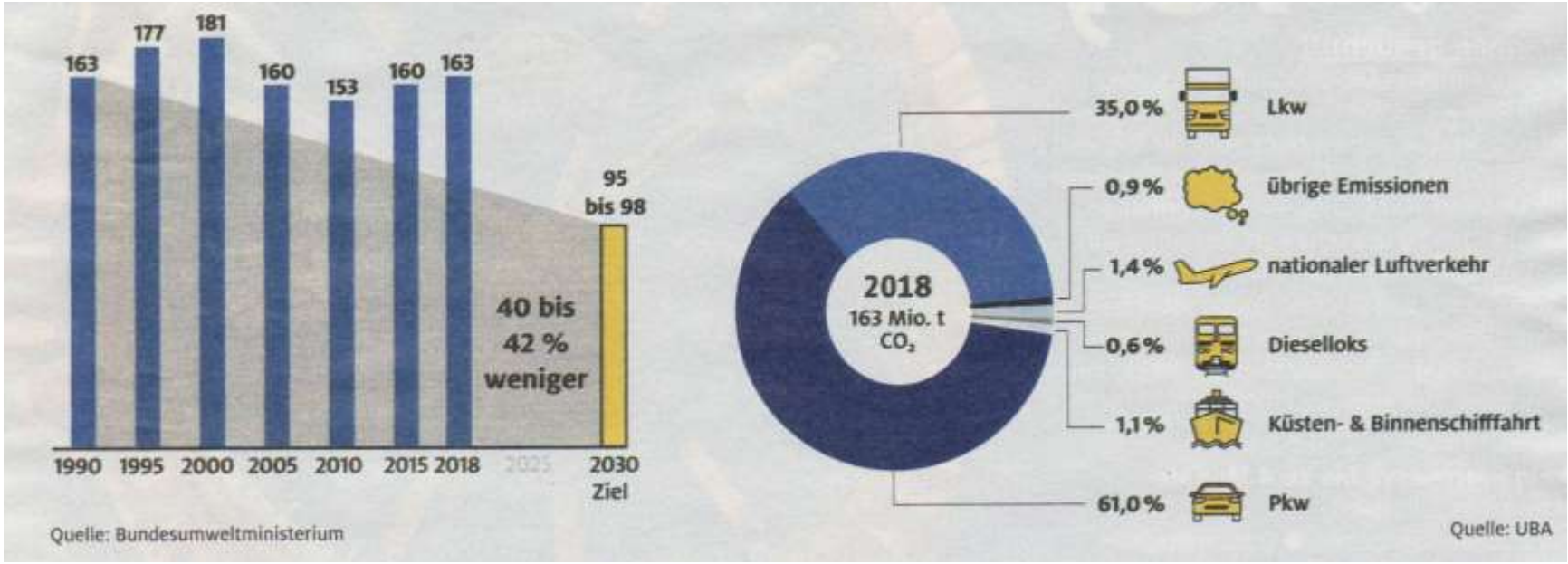


⇒ 50% of soil organic matter loss

Tiessen et al. (1994) Nature 371: 783–785

CO_2 emisssions Germany

1 kg CO_2 = 2 kg m^{-3} (0° C and 1013 hPa)
1000 kg CO_2 = 8 m x 8 m x 8 m = 512 m^3
Germany: Each person emits 12 tons of CO_2 per year => 6150 m^3 = 18 m x 18 m x 18 m



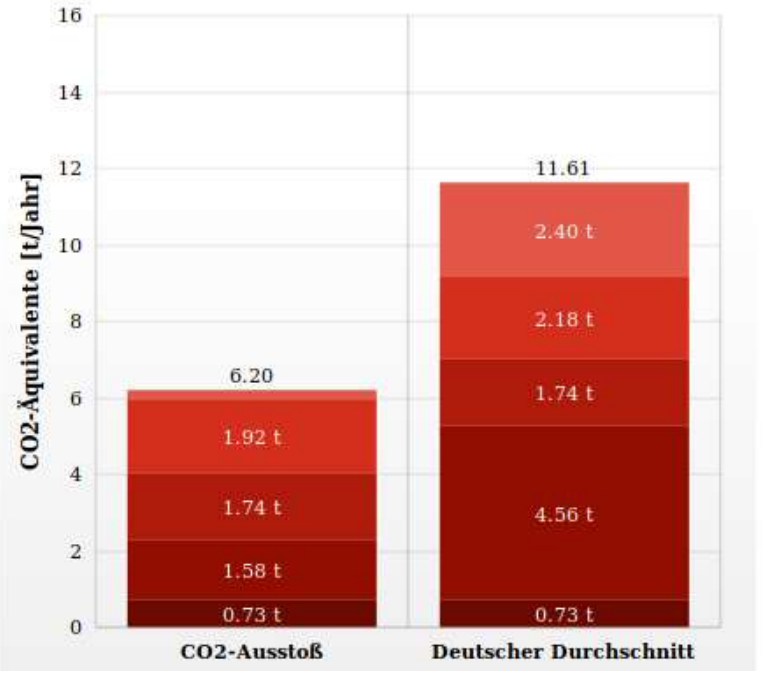
Quelle: Umweltbundesamt

Personal CO_2 emissions

CO_2 calculator of Umweltundesamt: www.uba.co2-rechner.de

	CO_2-Ausstoß	Deutscher Durchschnitt
Heizung	0,00 t	1,64 t
Strom	0,23 t	0,76 t
Mobilität	1,92 t	2,18 t
Ernährung	1,74 t	1,74 t
Sonstiger Konsum	1,58 t	4,56 t
Öffentliche Emissionen	0,73 t	0,73 t
Ergebnis	6,19 t	11,60 t

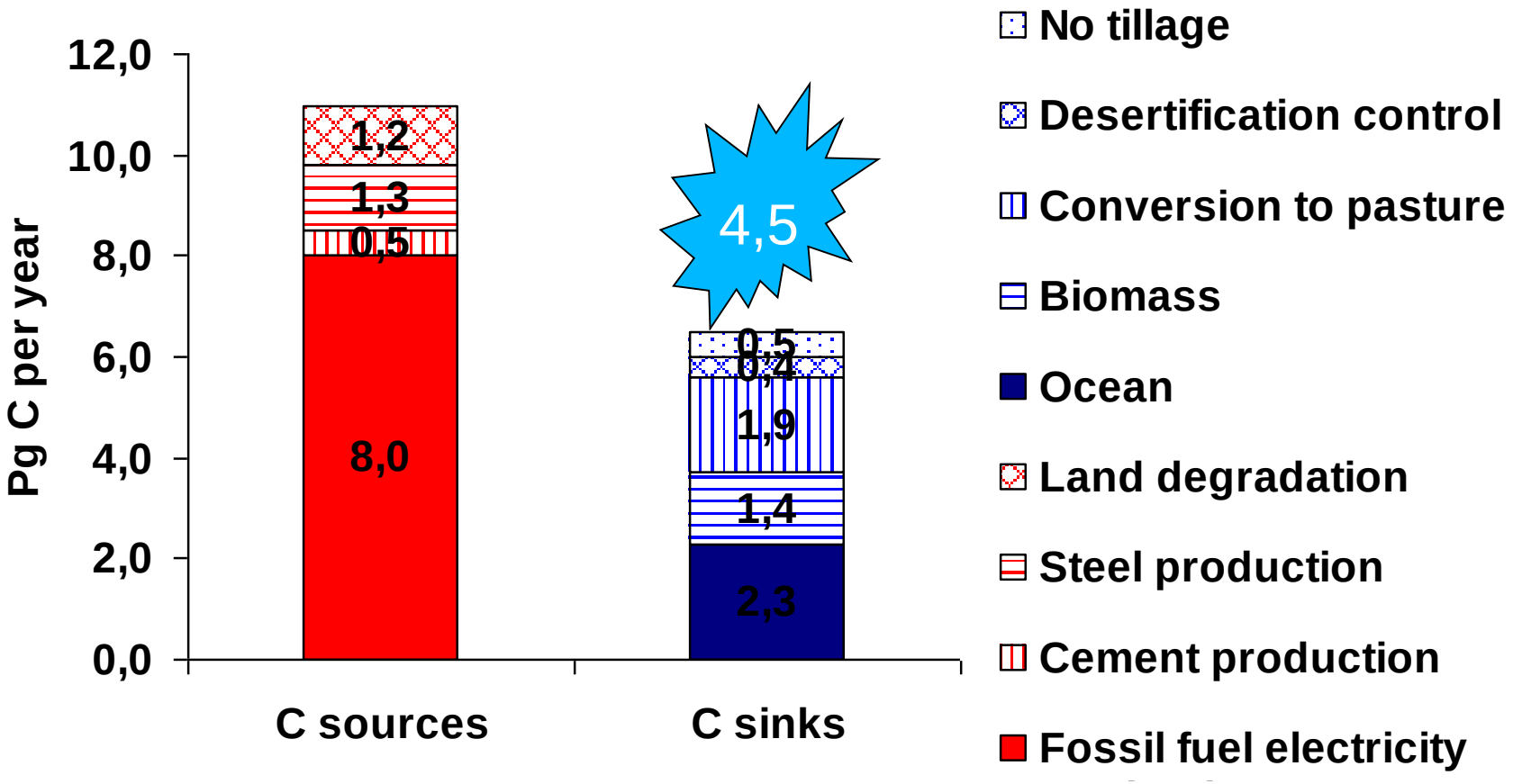
Wie Sie Ihre CO_2-Bilanz für die Zukunft optimieren erfahren Sie in **Mein CO_2-Szenario**.



Quelle: Umweltbundesamt

Soils as sources and sinks of CO_2

1 Pg (Petagramm) (10^{15}g)
= 1 Gigatonne (Gt)
= 10^9 Tonnen



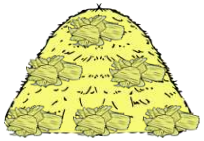
Glaser, B. (2011) Biochar use: a productive alternative to carbon storage. In "COP 17 United Nations Climate Change Conference", Vol. Produced for: COP 17, United Nations Climate Change Conference, Durban, pp. 137-139. Green Media in partnership with the United Nations Environment Programme (UNEP), Durban, South Africa.

Terra Preta: 2000 years old soil experiment

Ferralsol

Organic waste

Litter



Food leftovers

Bones

Compost / faeces

Biochar

Microorganisms

Terra Preta

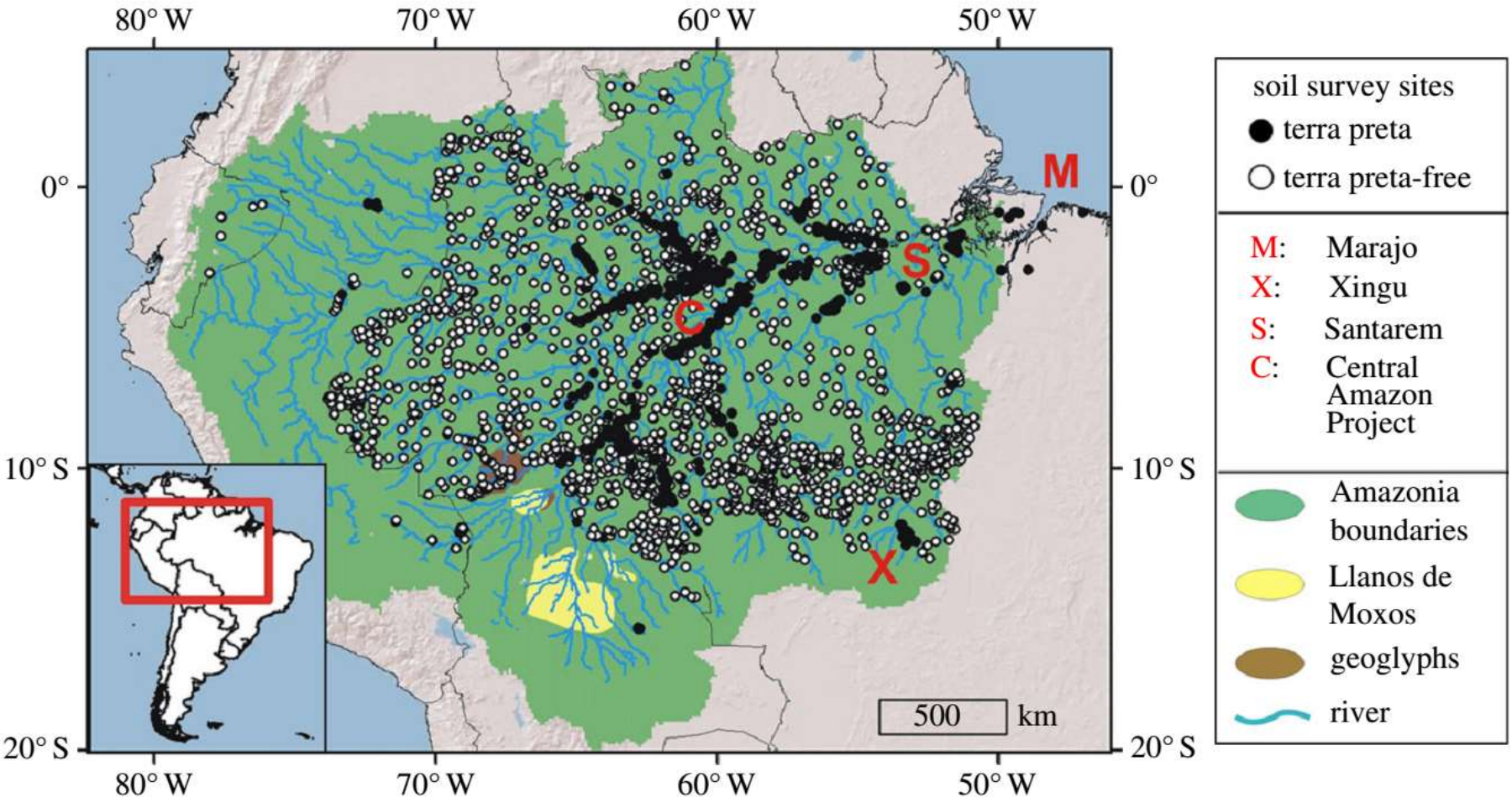
⇒ ***Ancient settlement sites***

⇒ ***Unintentional rather than intentional for agriculture***

⇒ ***Most probably later use for agriculture (homegardens, agroforestry)***

Glaser et al. (2001) Naturwissenschaften 88: 37-41

Significant ocurrence?



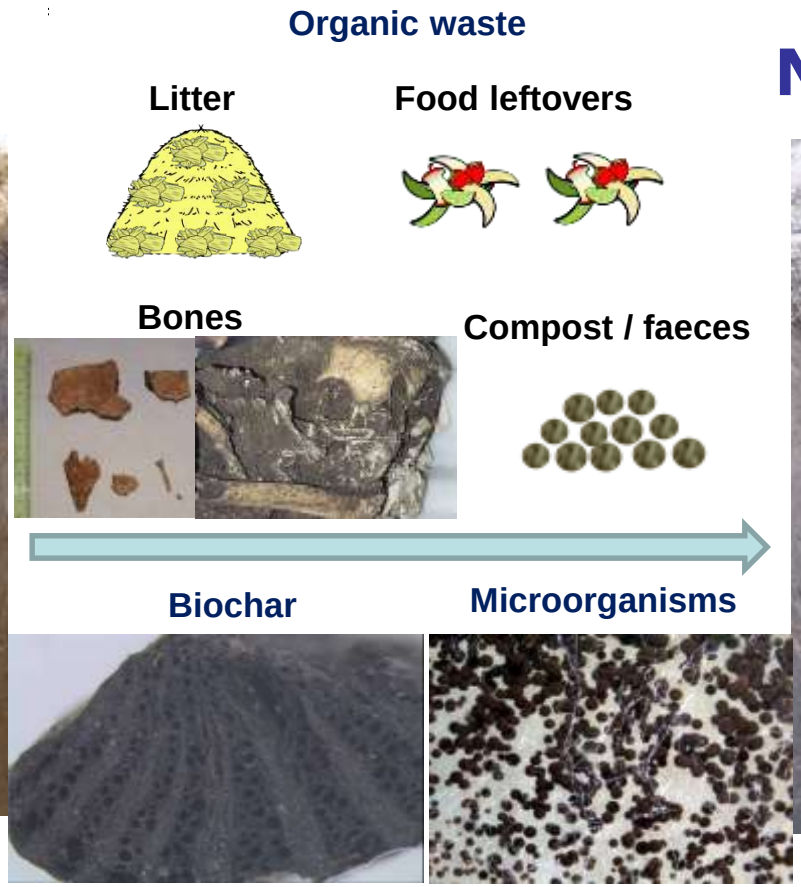
⇒ ***Model: MAXENT v. 3.3.3 (http://www.cs.princeton.edu/~schapire/maxent/)***

⇒ ***154.063 km² (3,2%)***

McMichael et al (2014) Proc. Roy. Soc. B 281, 20132475

Nordic Dark Earth

Cambisol



Nordic Dark Earth

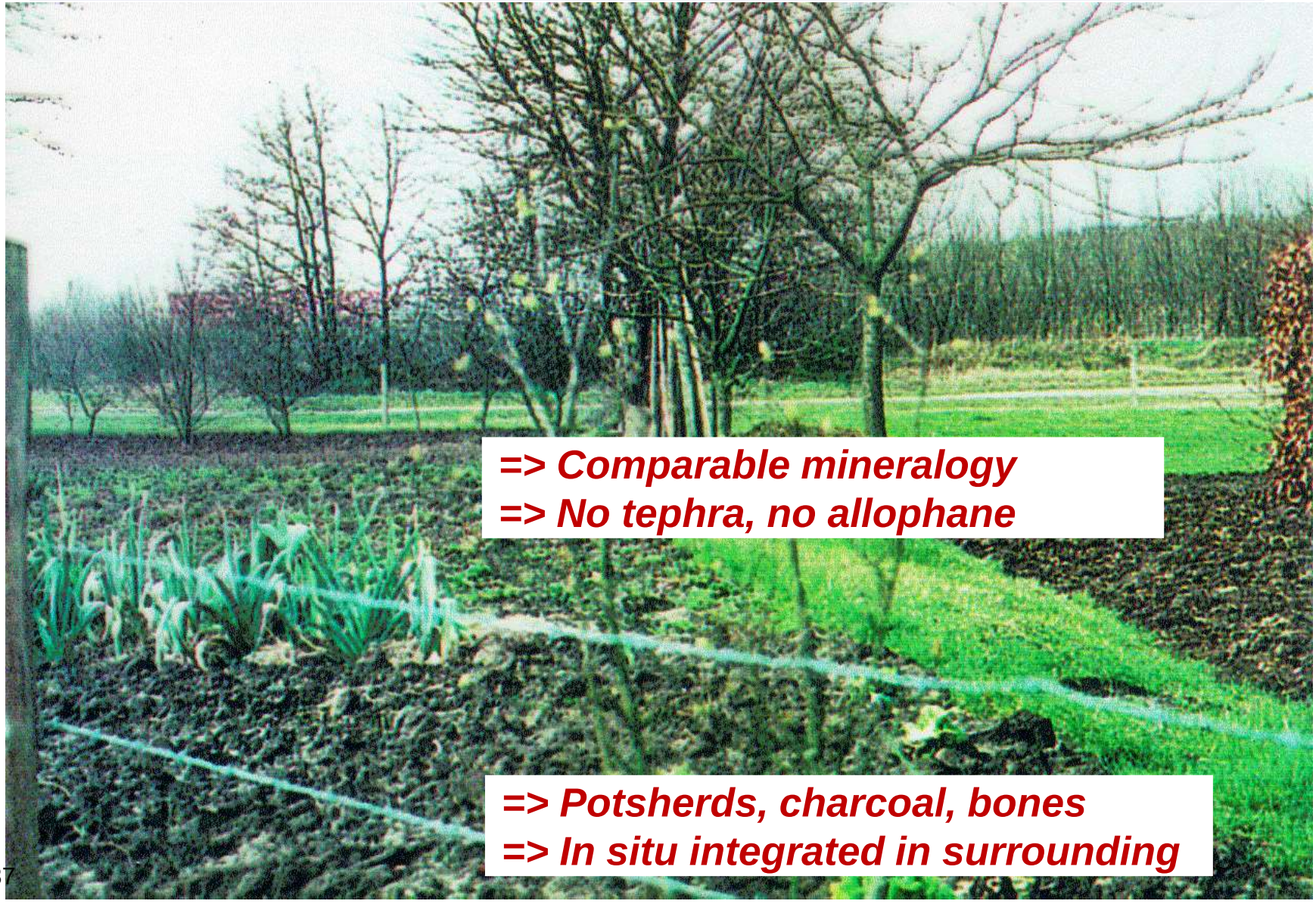
⇒ ***Genesis and properties similar to Terra Preta***

⇒ ***Pretic Anthrosols***

Wiedner et al. (2015) Catena 132: 114 - 125


© Bruno Glaser

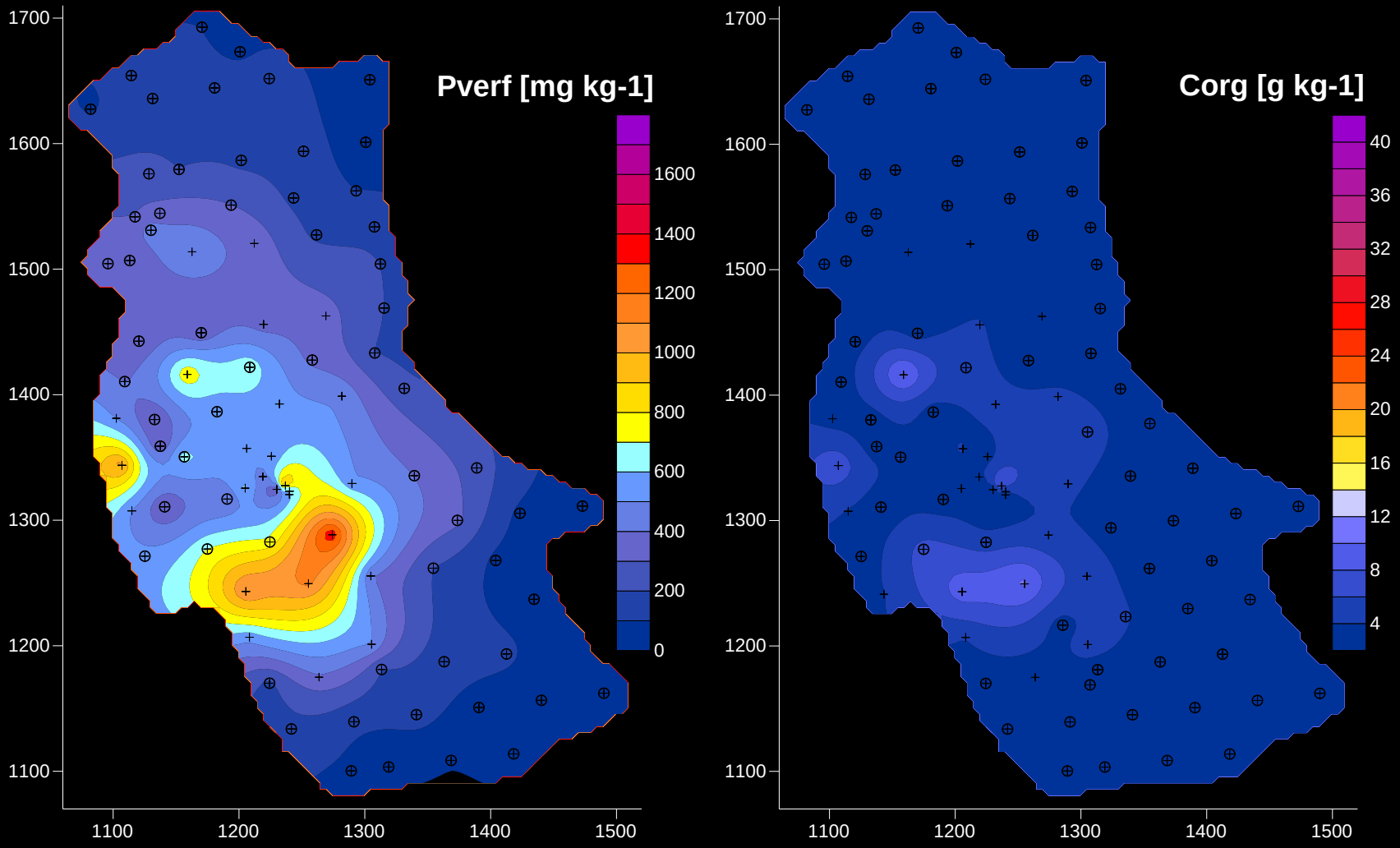
Genesis


=> Comparable mineralogy
=> No tephra, no allophane
=> Potsherds, charcoal, bones
=> In situ integrated in surrounding

Sitio Hatahara

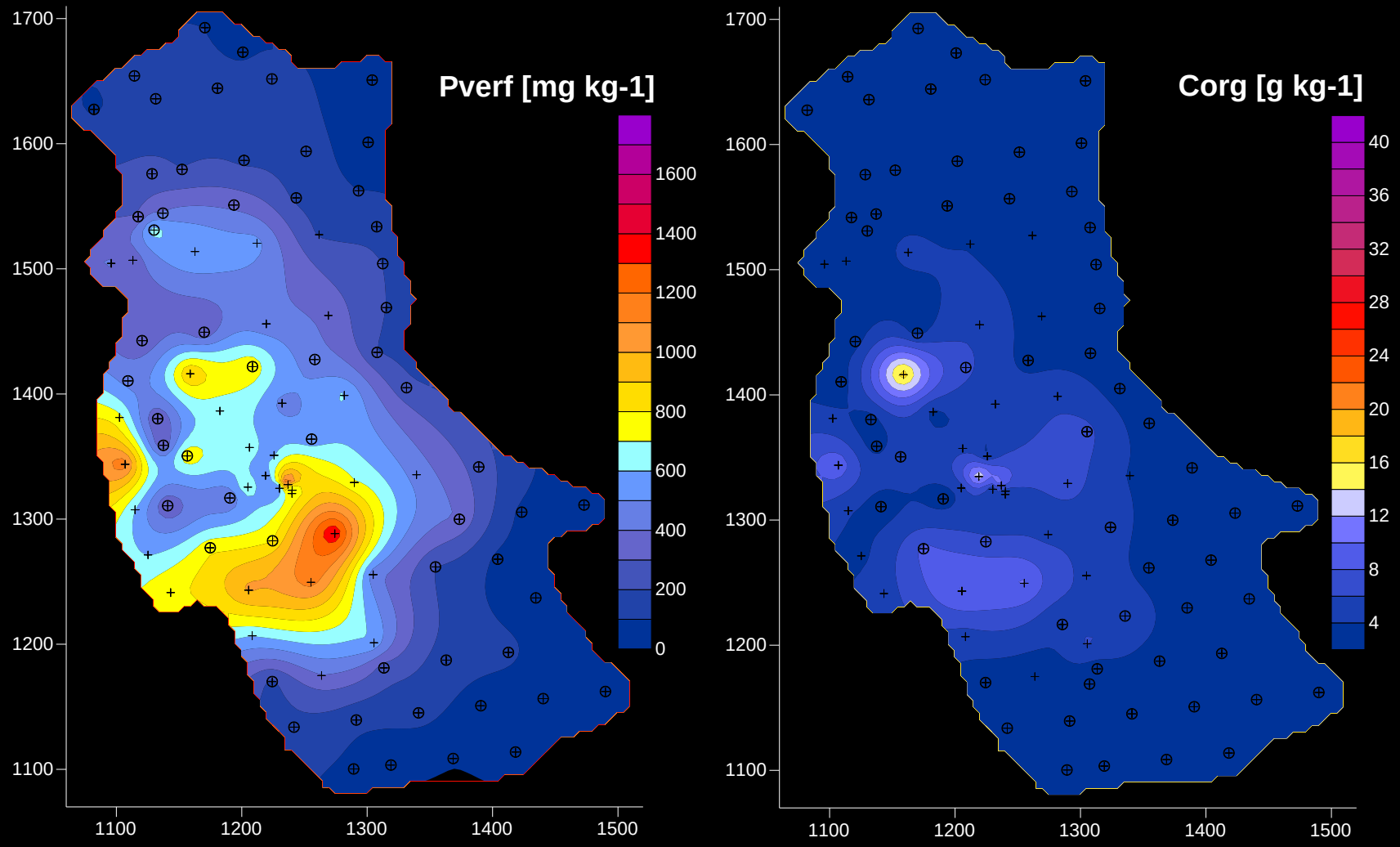
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

Nutrients 200 – 180 cm



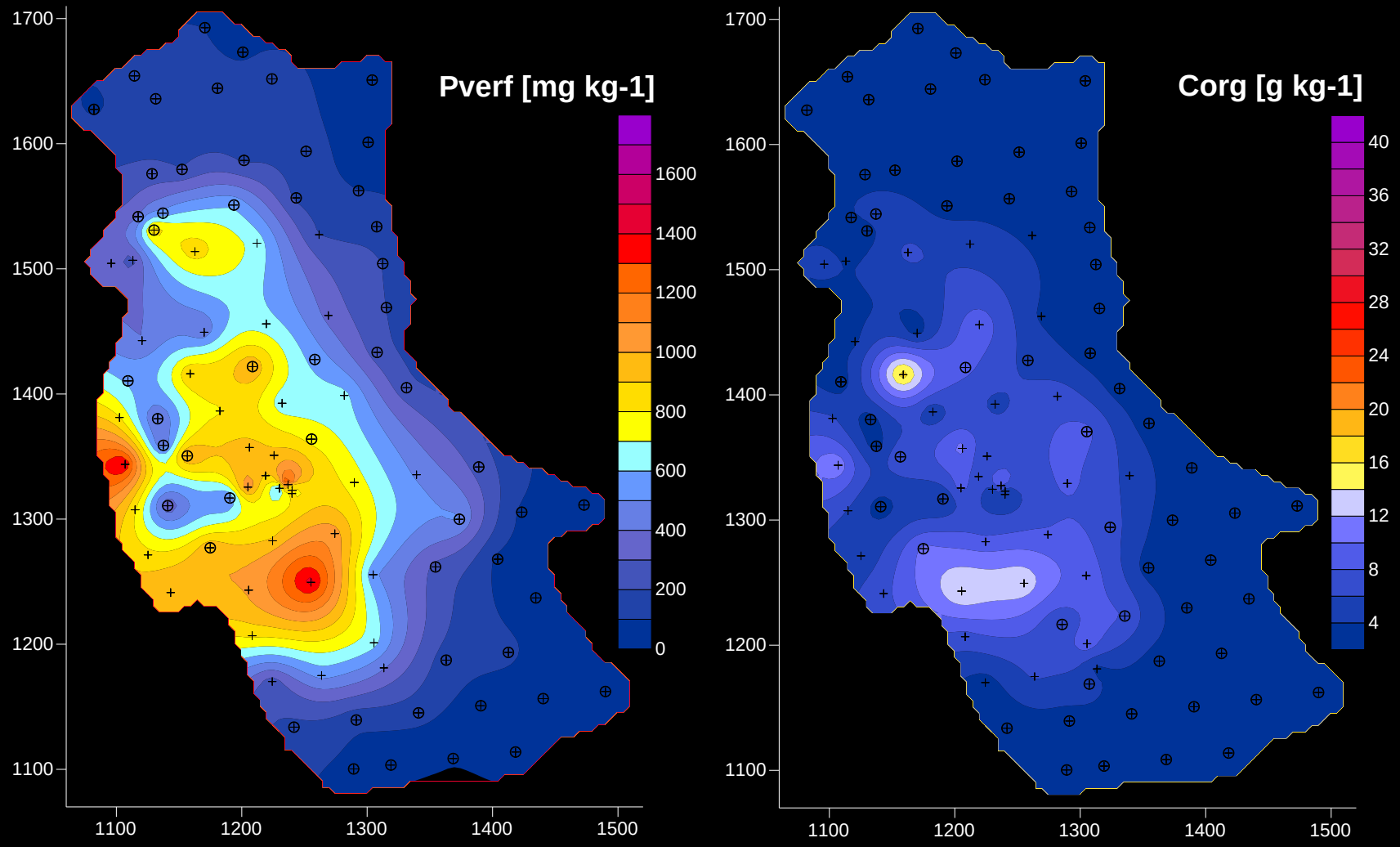
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

Nutrients 180 – 160 cm



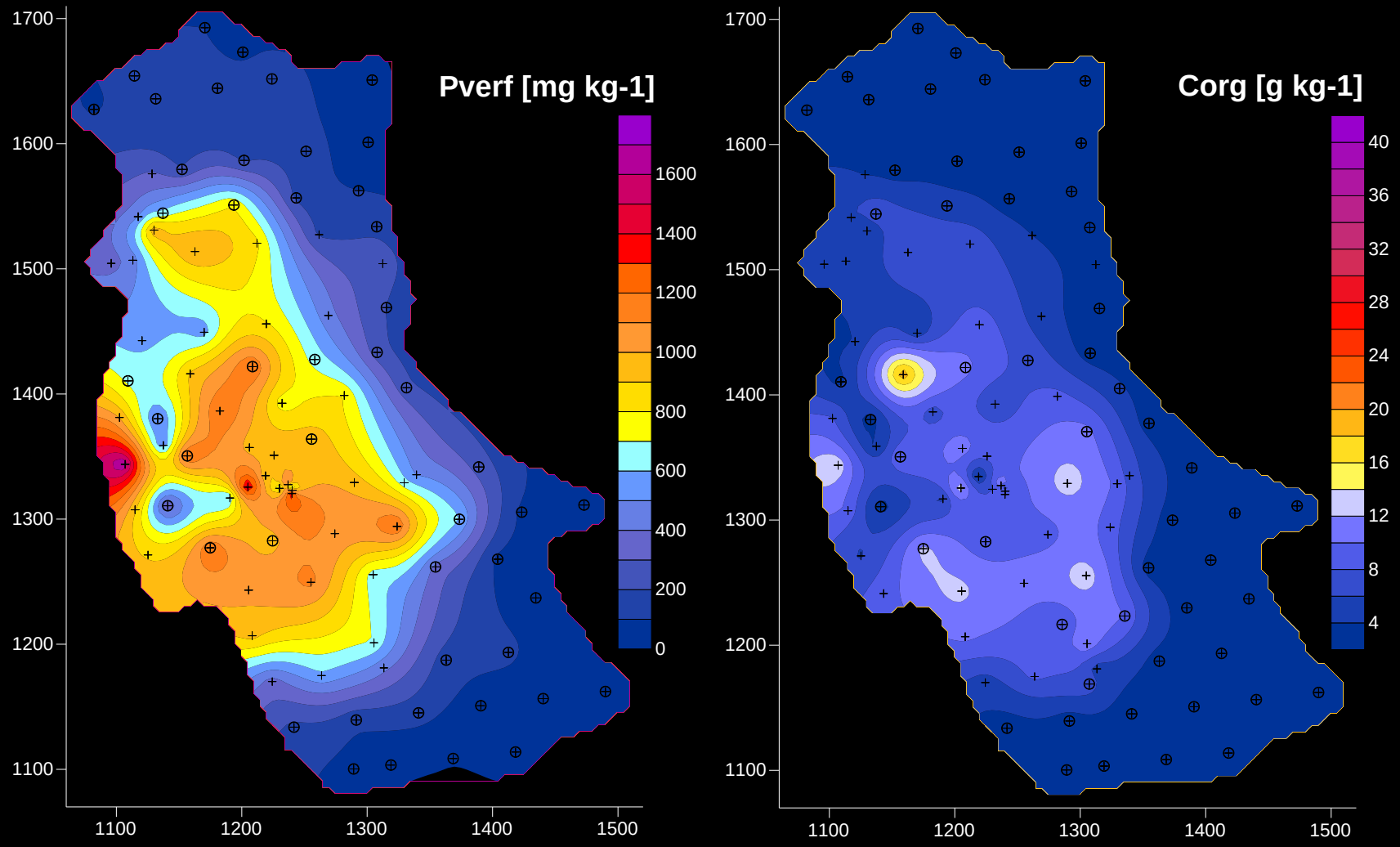
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

Nutrients 160 – 140 cm



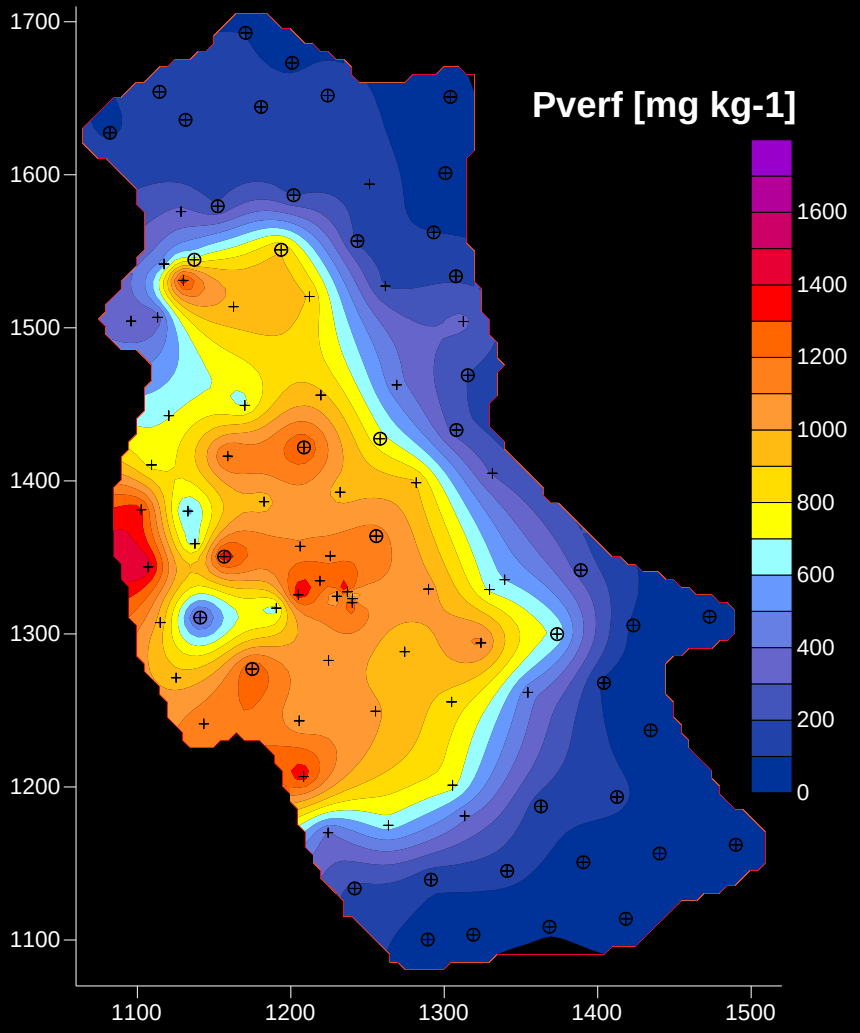
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

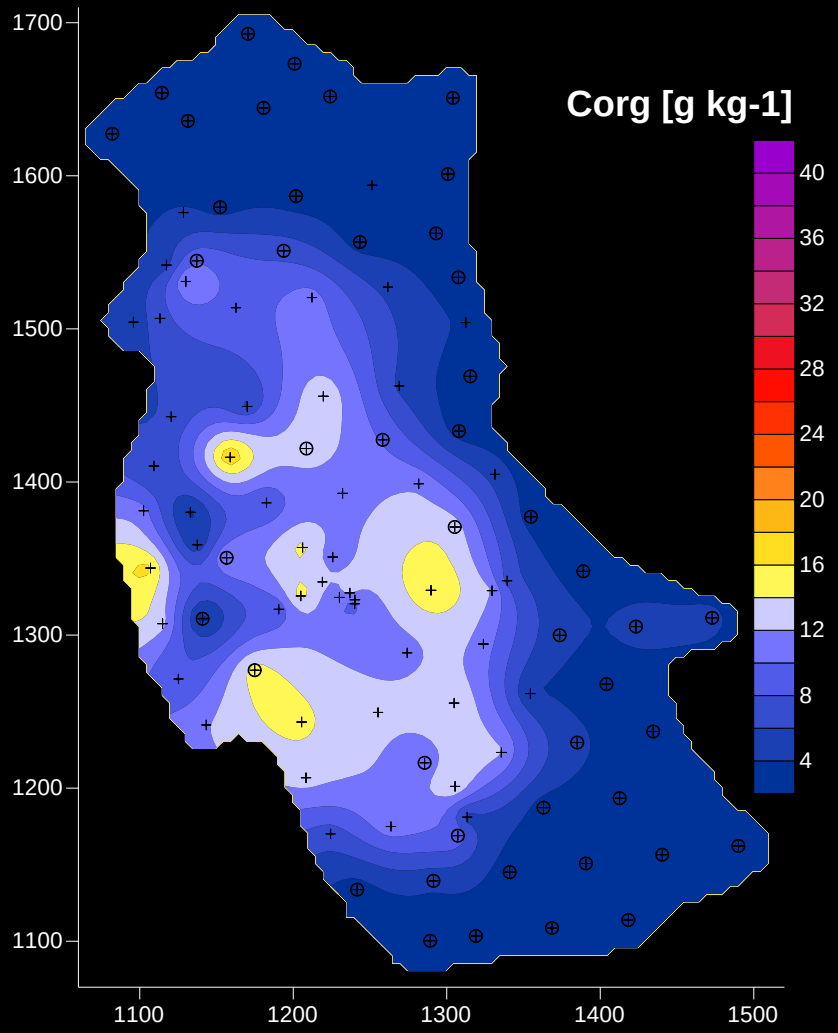
Nutrients 140 – 120 cm



Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

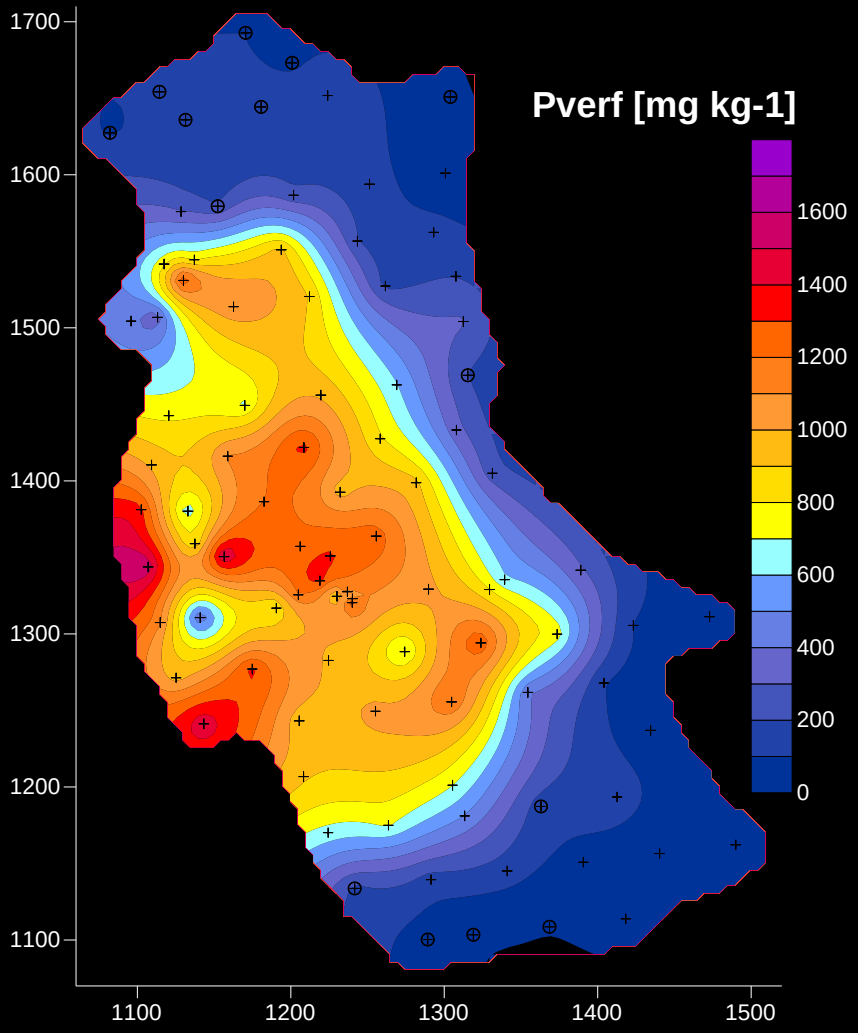
Nutrients 120 – 100 cm

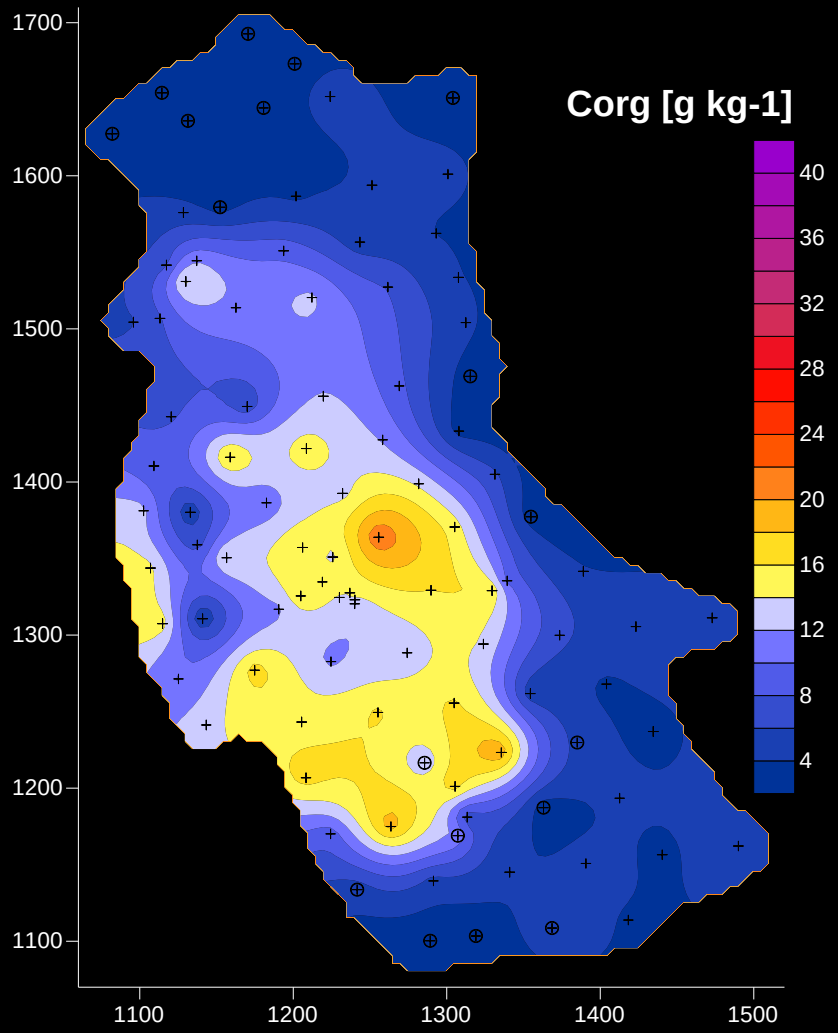




Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

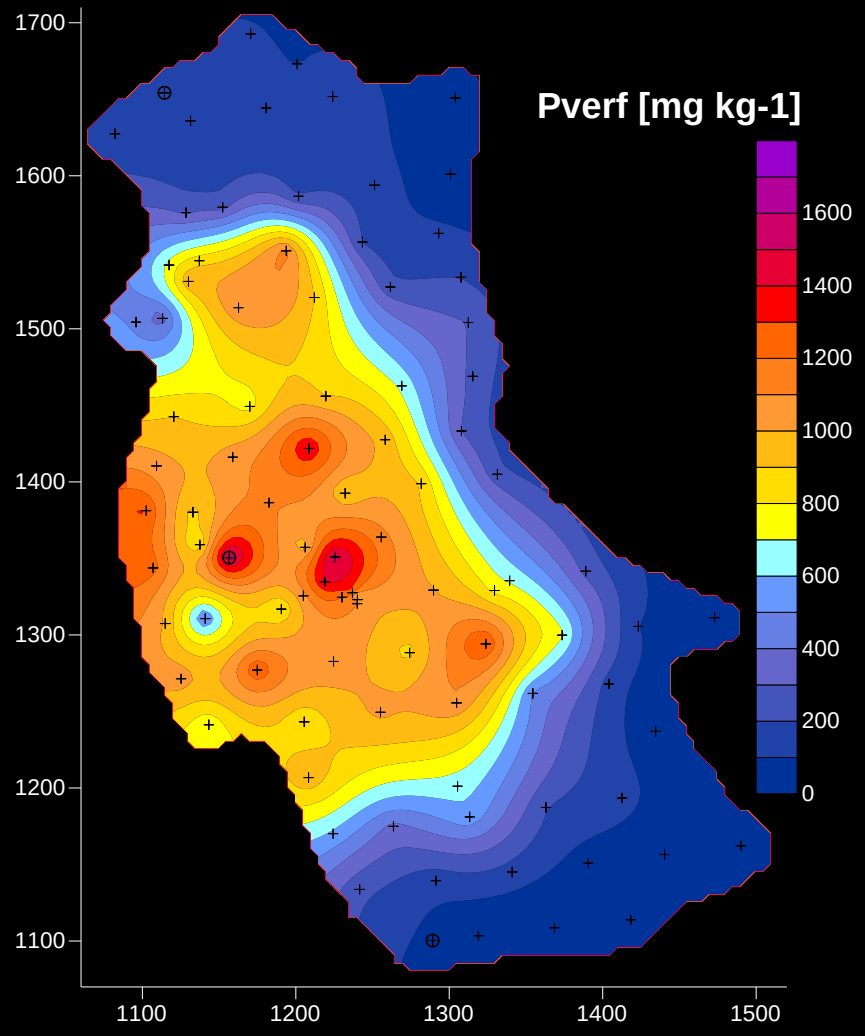
Nutrients 100 – 80 cm

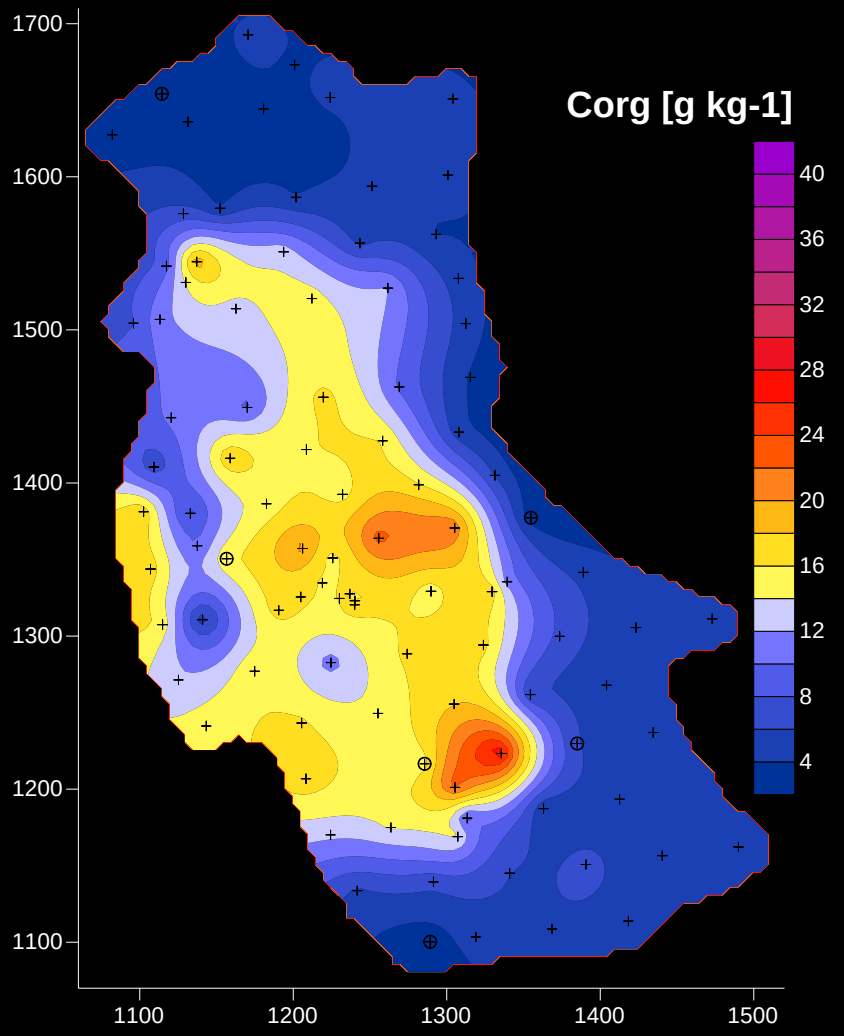




Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

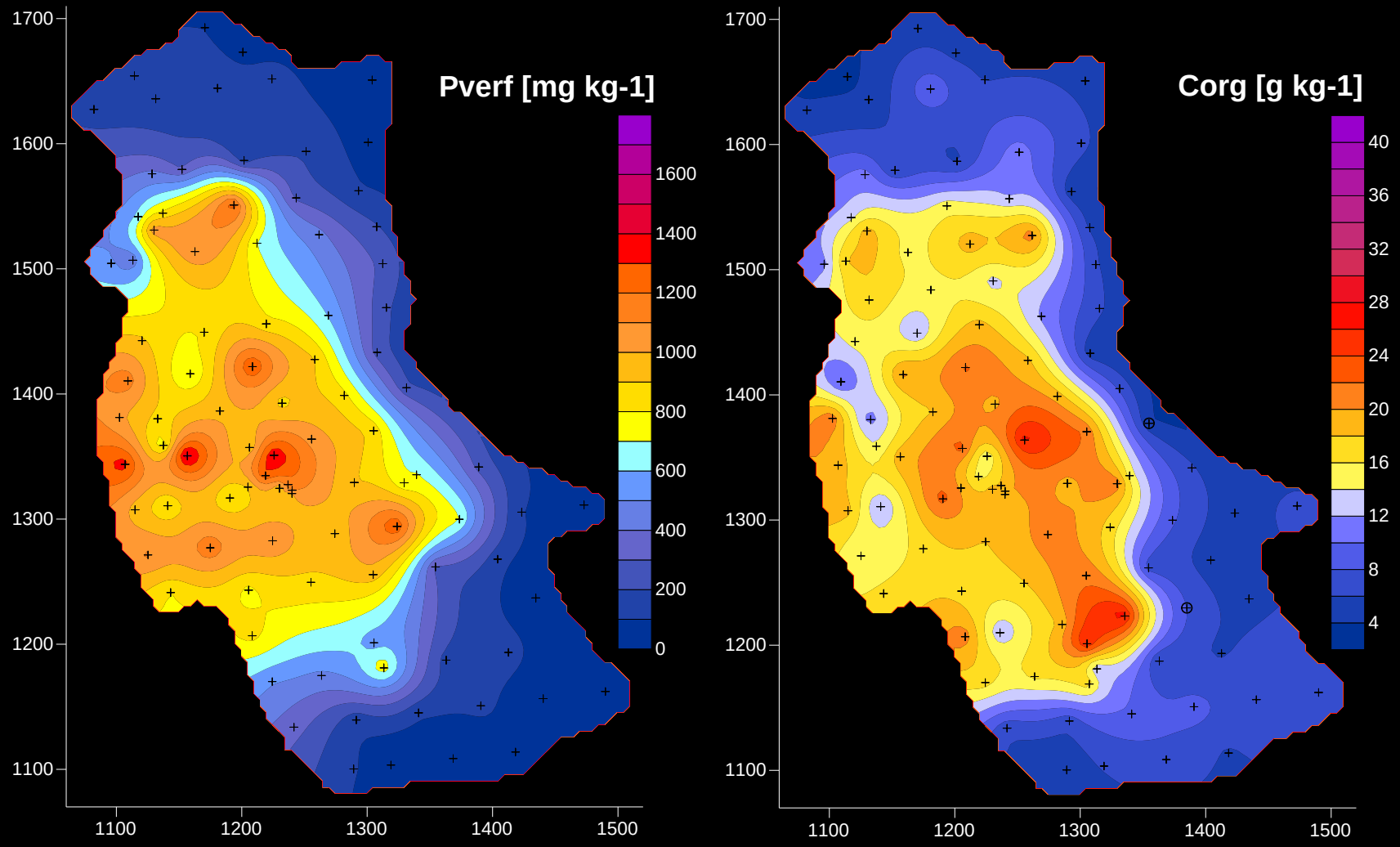
Nutrients 80 – 60 cm





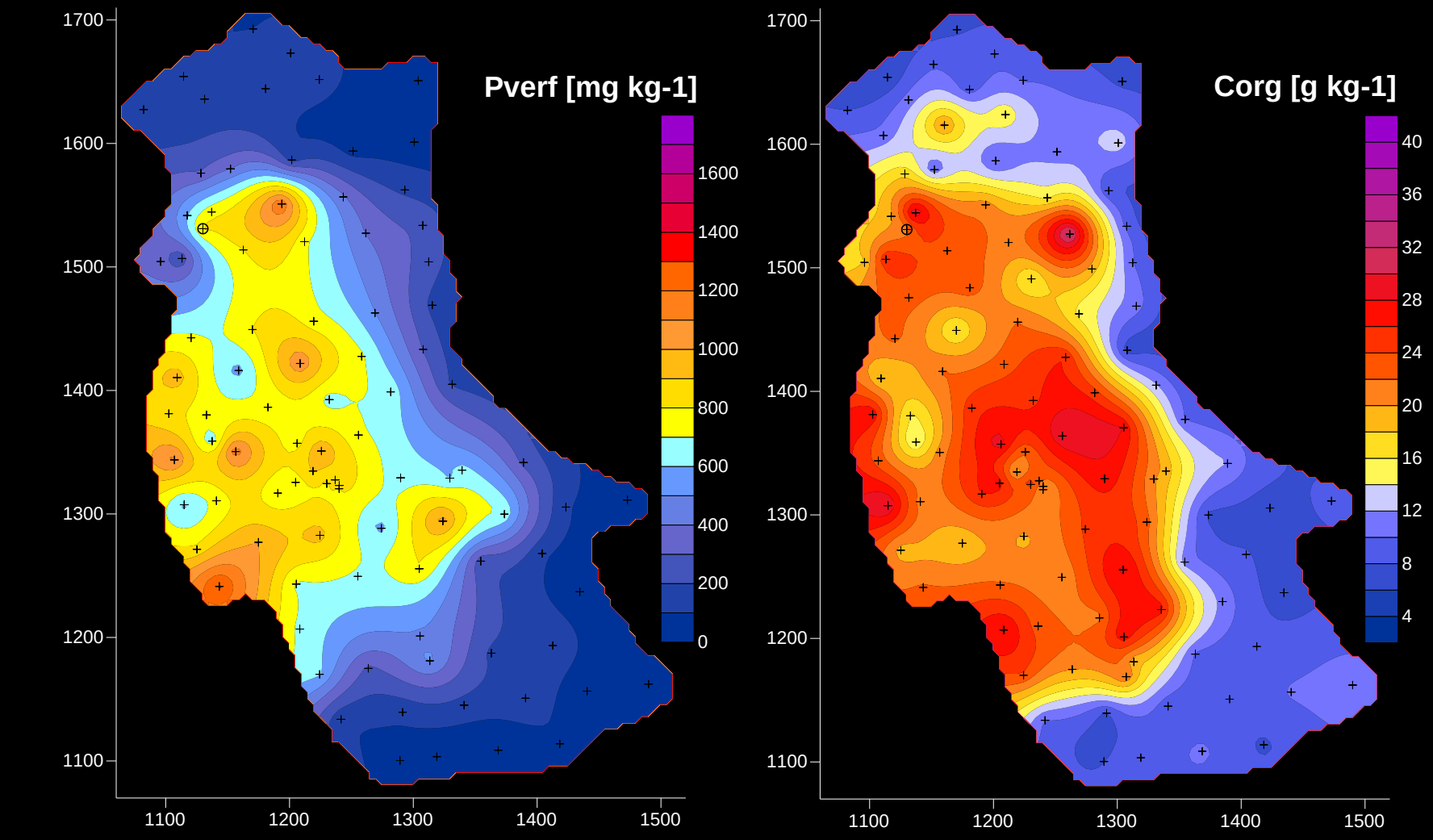
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

Nutrients 60 – 40 cm



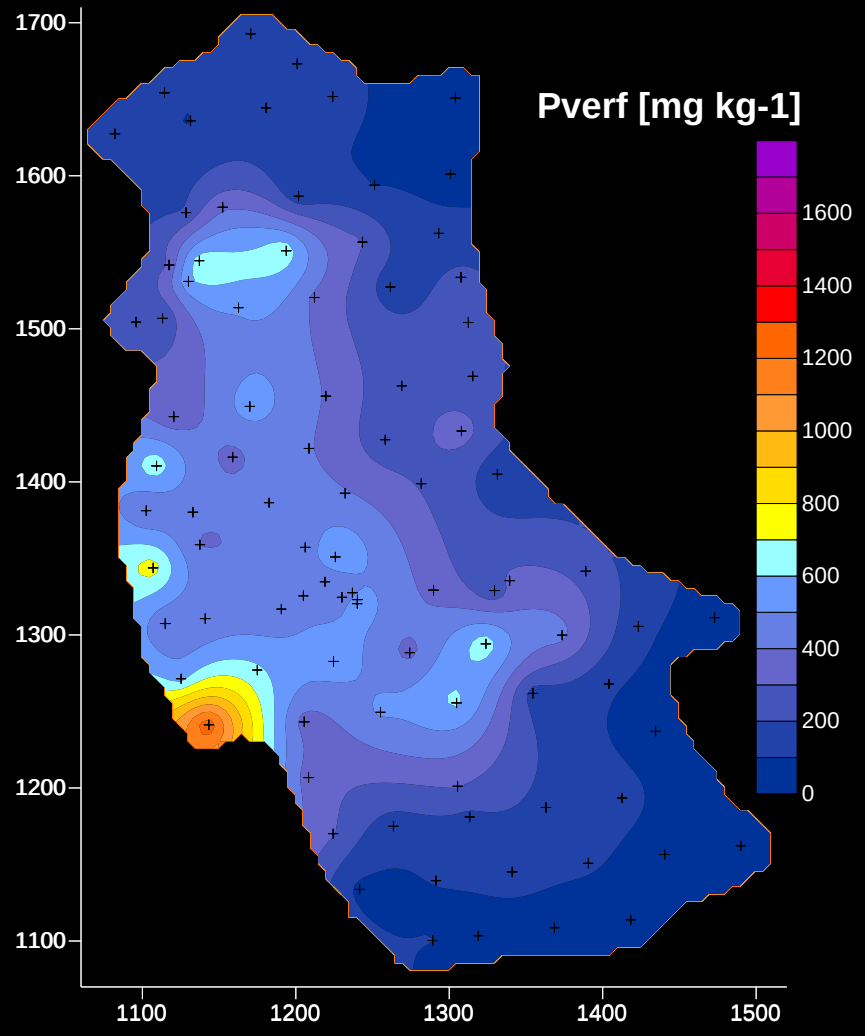
Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

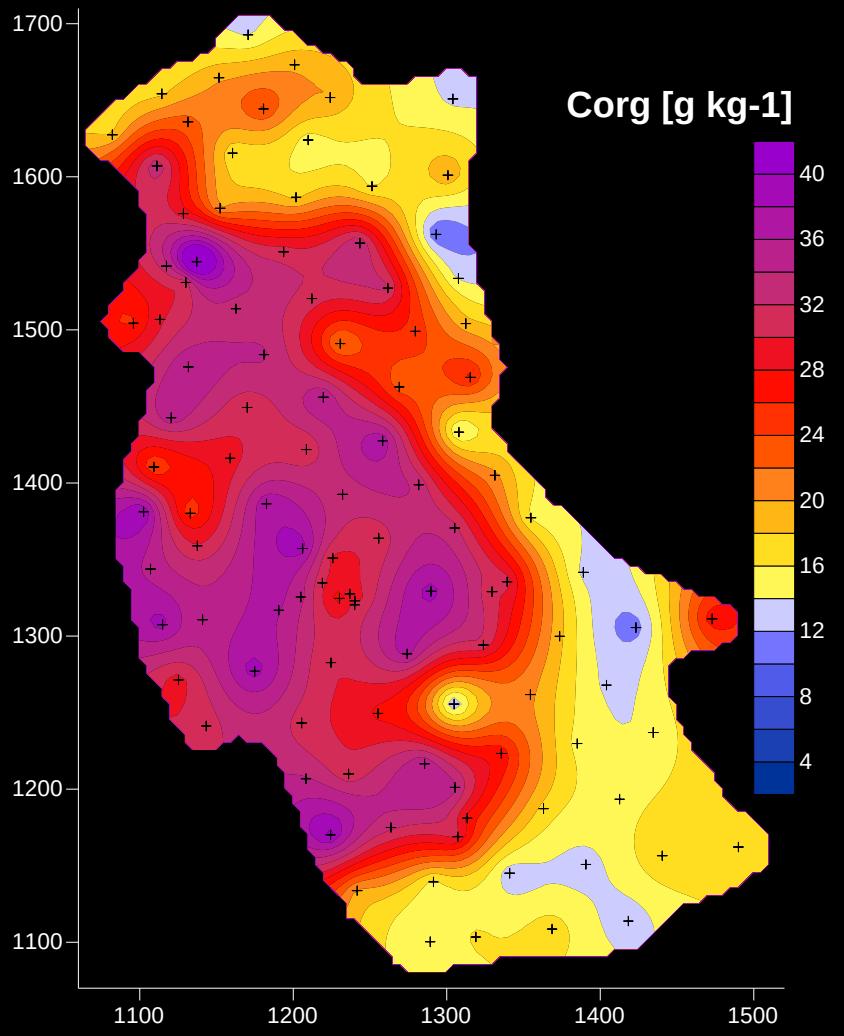
Nutrients 40 – 20 cm



Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

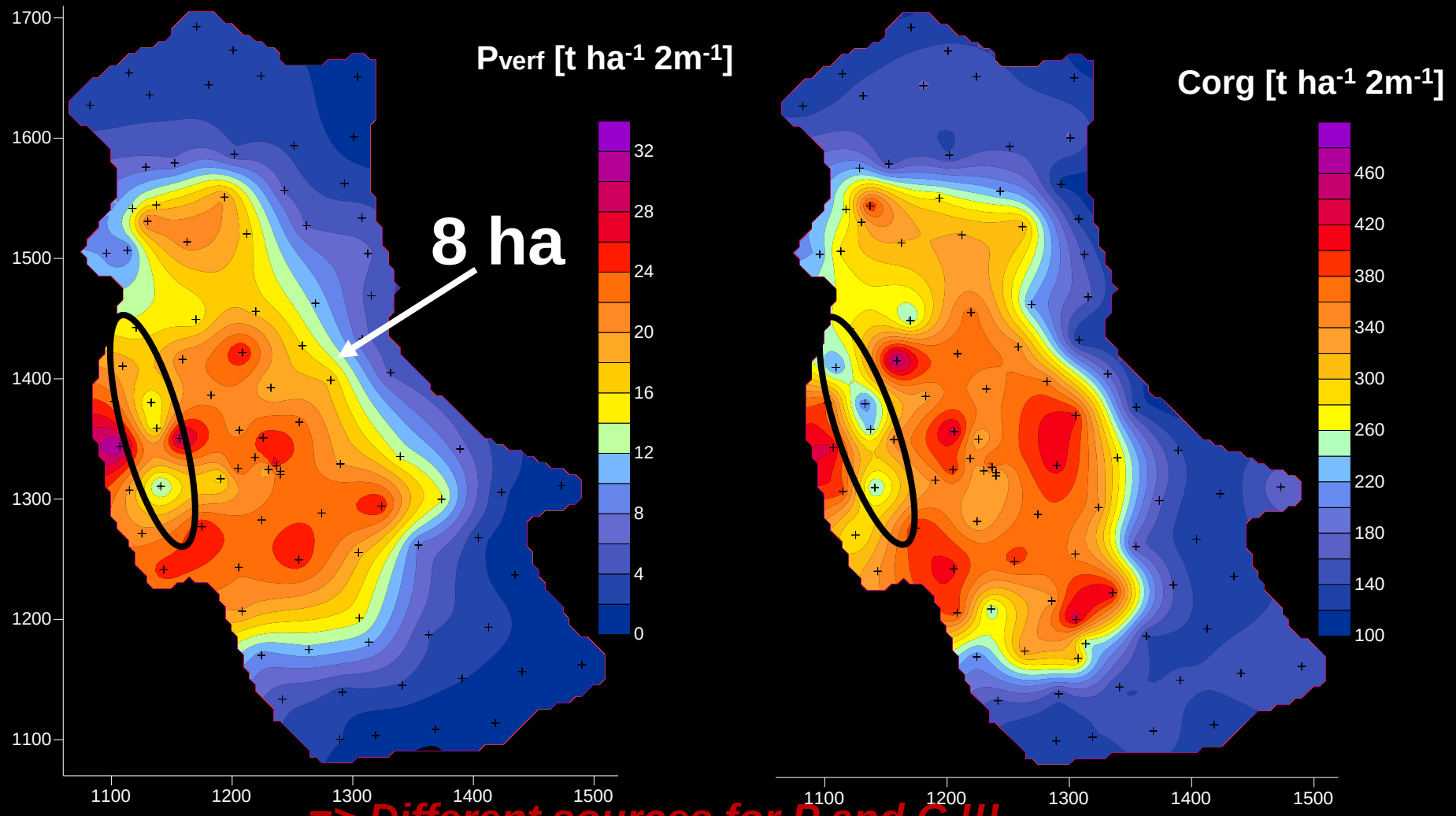
Nutrients 20 – 0 cm





Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

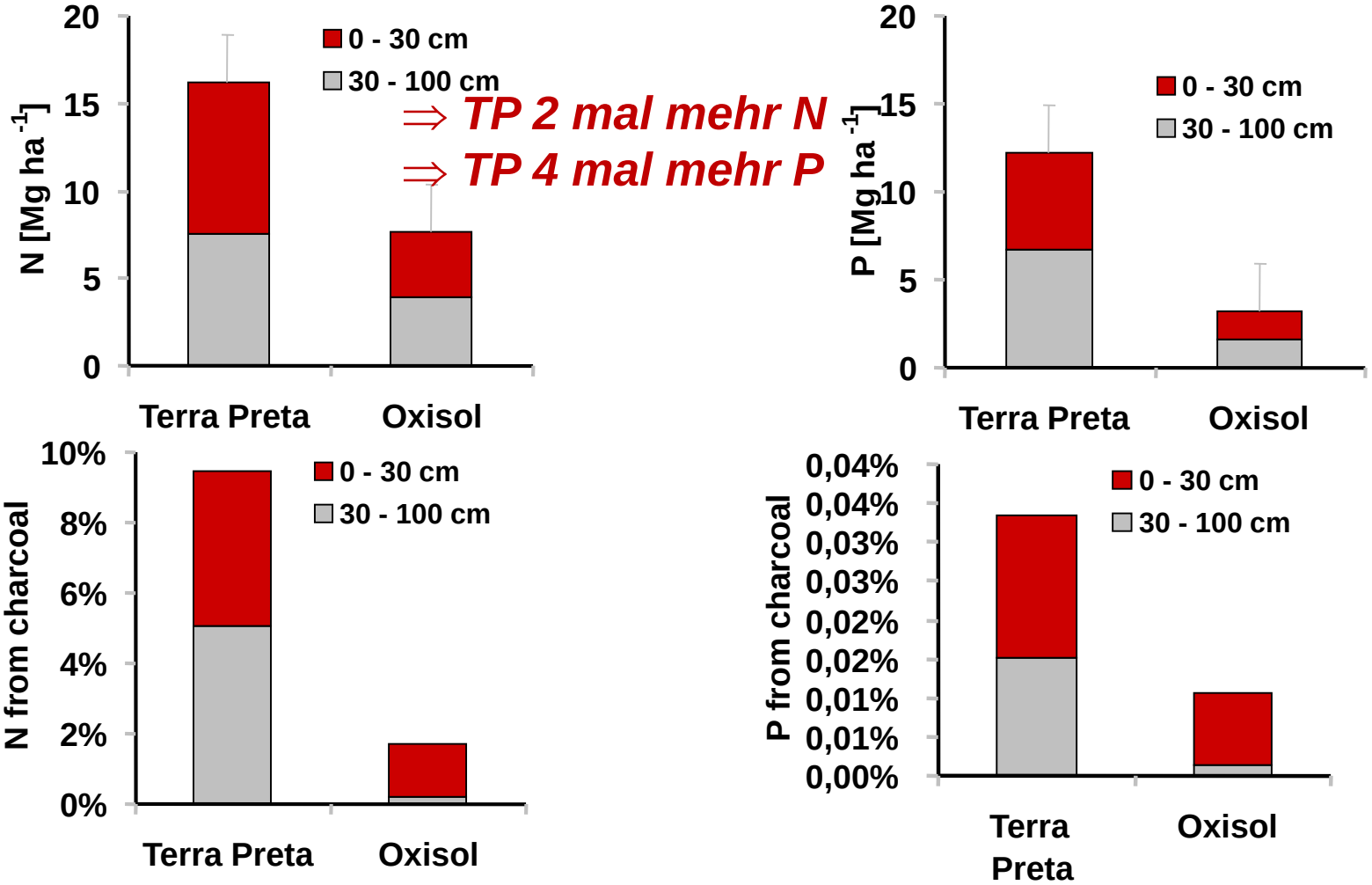
Nutrient stocks 0 – 200 cm



=> Different sources for P and C !!!

Birk et al (2007) Mitt Dt Bodenkundl Ges 110, 643-644

N and P stocks



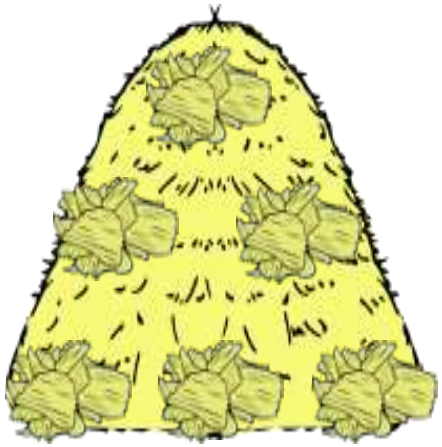
Glaser et al (2003) Organic Chemistry Studies on Amazonian Dark Earths. In: Lehmann, J., Kern, D., Glaser, B., Woods, W. (Hg.): Amazonian Dark Earths: Origin, Properties, and Management. Dordrecht, The Netherlands: Kluwer, S. 227–241.

Where do the nutrients come from?

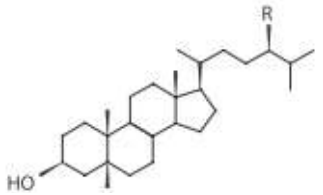
Potential nutrient sources

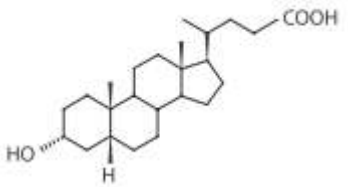
Garbage (Fish) bones

Compost Organic fertilizers

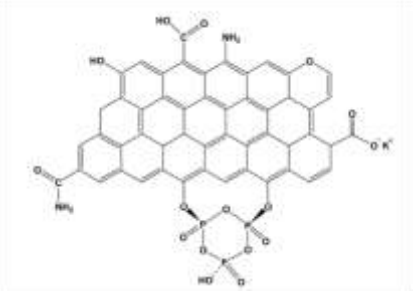


Human/animal excrements





Ash Biochar



⇒ ***SEM/EDX***

⇒ ***$\delta^{15}N$ AS***

⇒ ***Stanols***
Bile acids

⇒ ***Black Carbon***

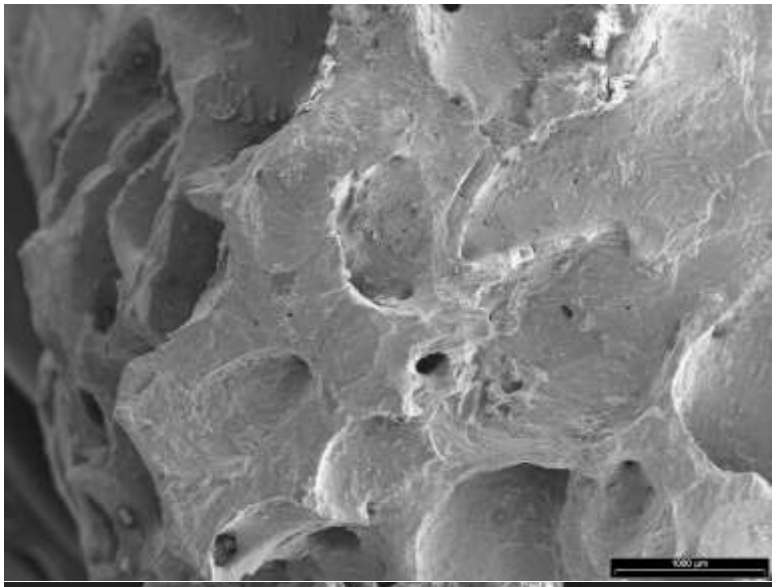
Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

Fish(bones)

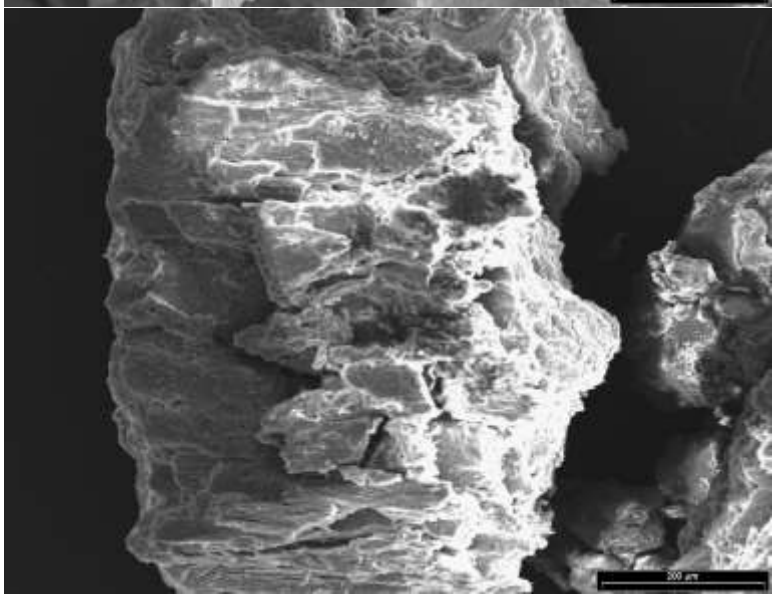
Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

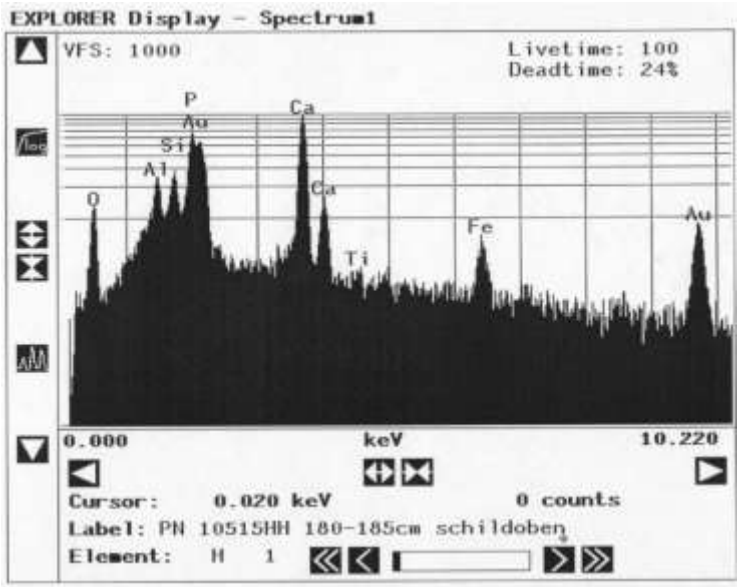
SEM/EDX

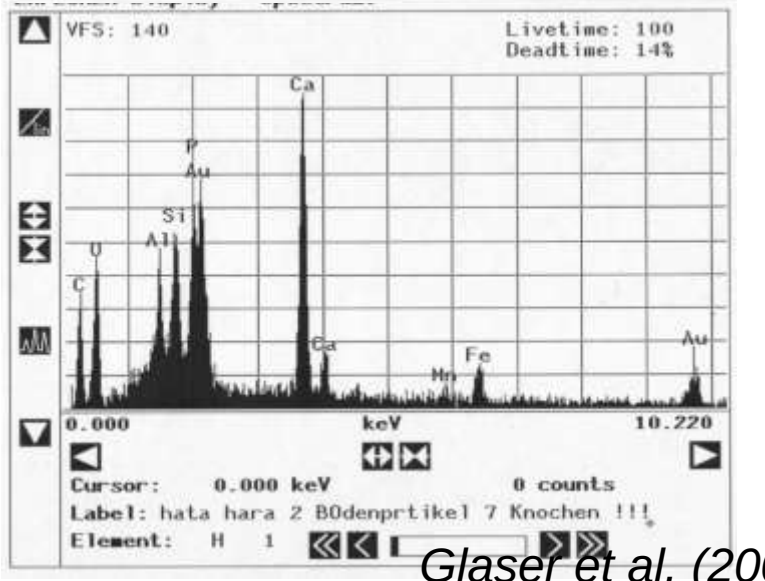
Turtle back



Terra Preta



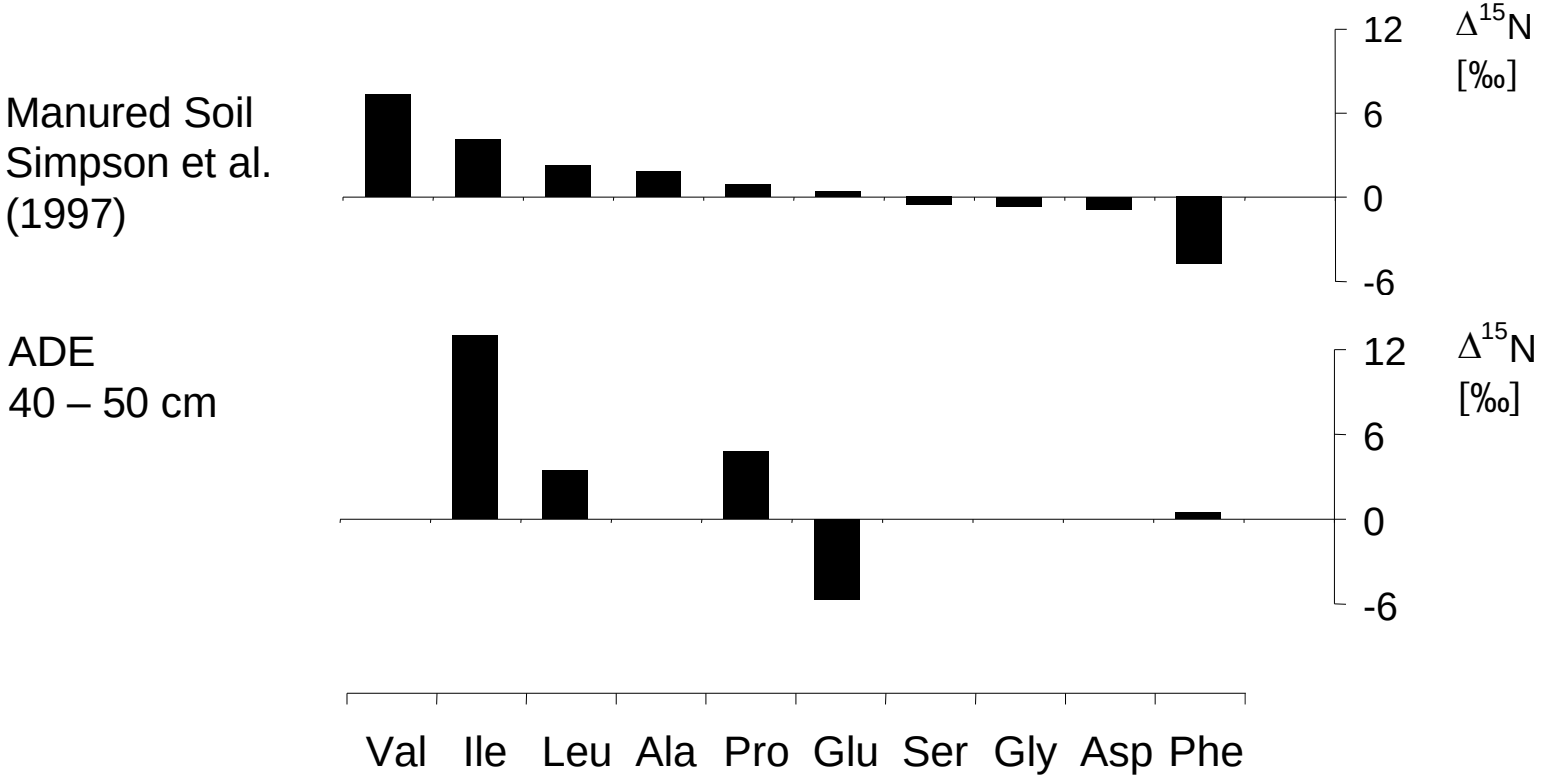




Glaser et al. (2003)

Compost / organic fertilizer

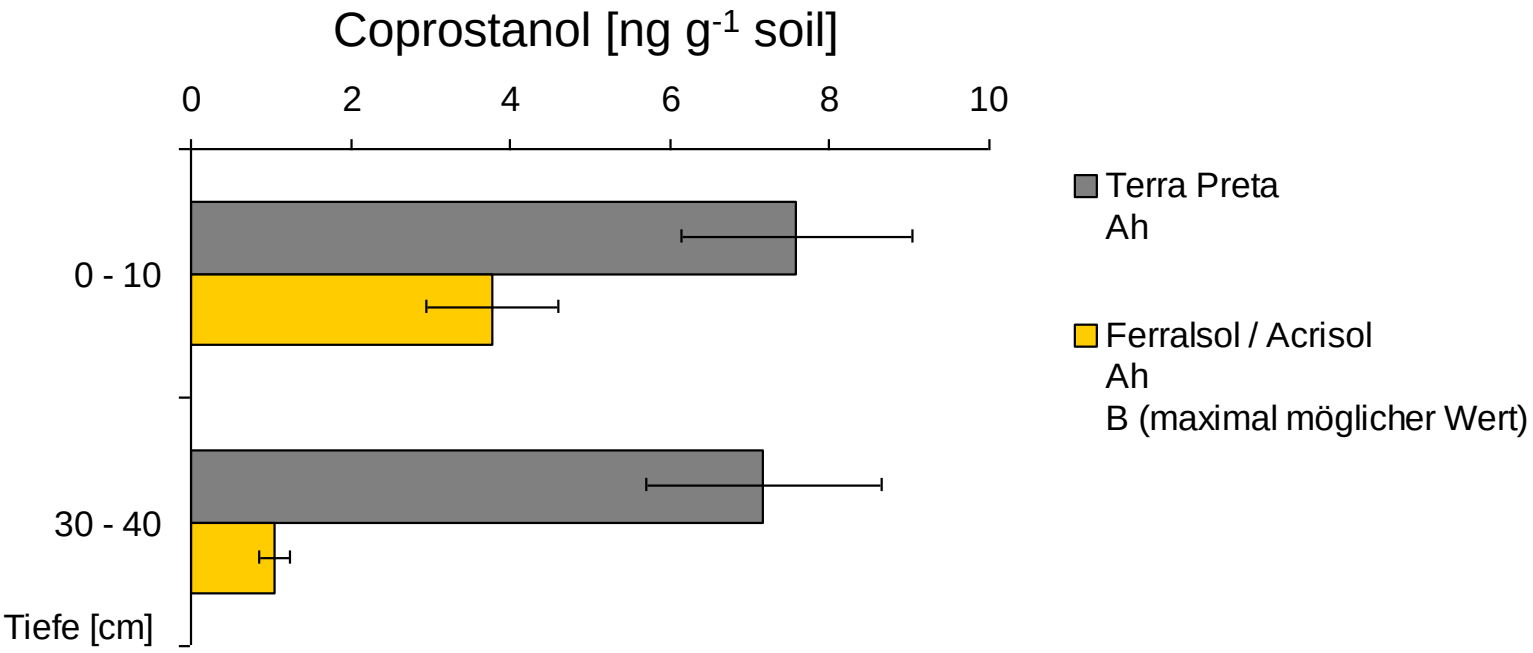
$\delta^{15}N$ **Amino acid**



⇒ ***Use of compost and / or organic fertilizers***

Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

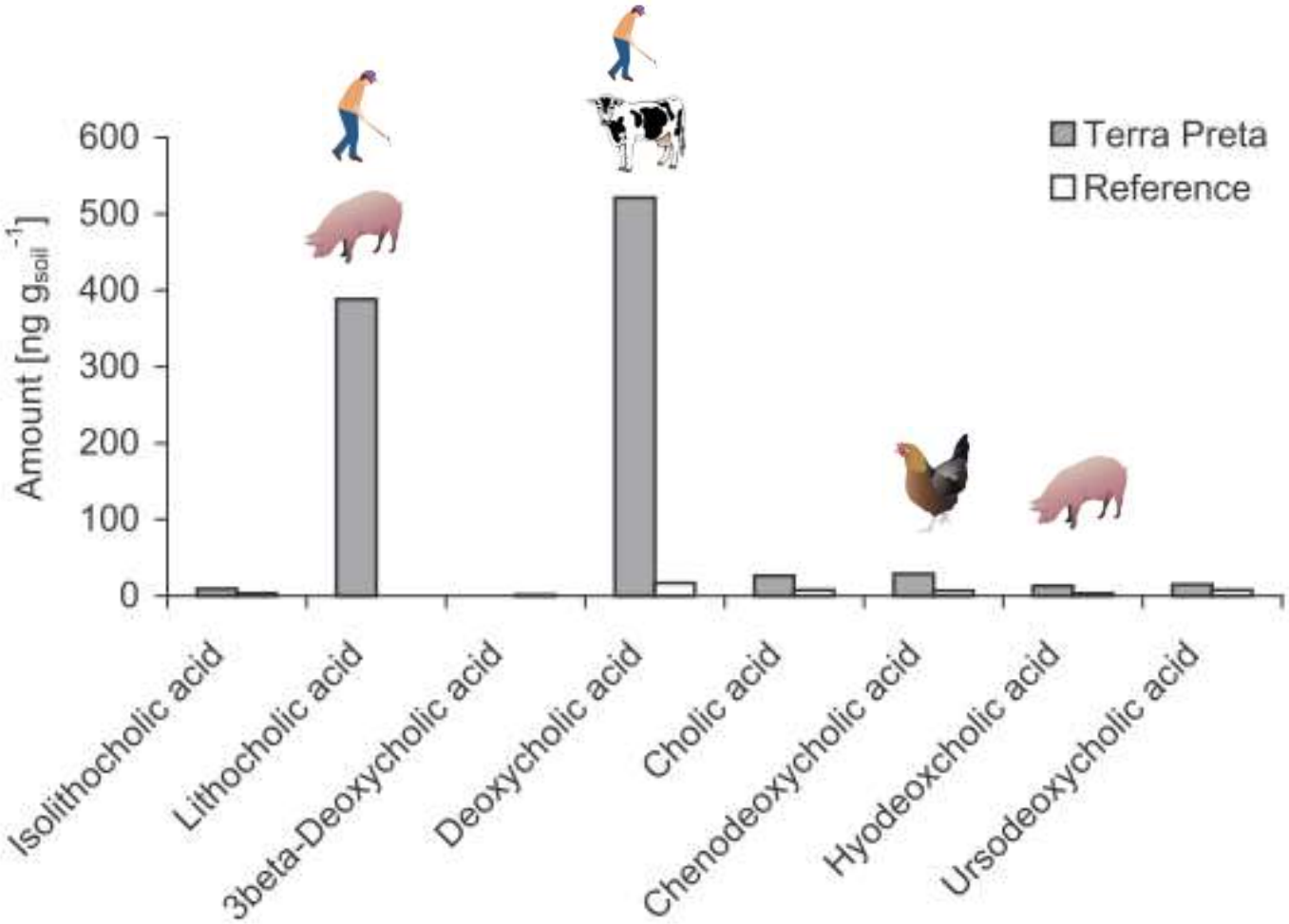
Coprostanol as faecal indicator



⇒ ***Excrements partly responsible for high nutrient content of Terra Preta***

Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

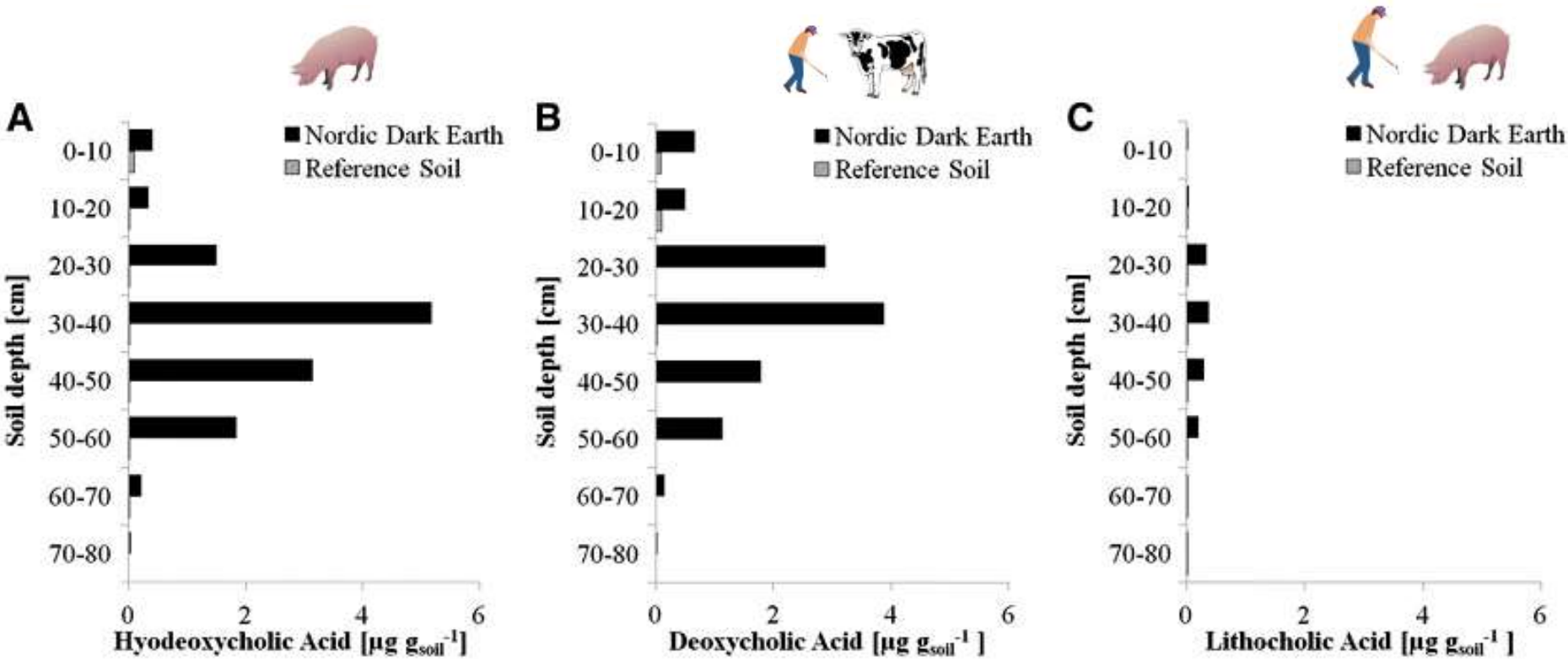
Bile acids: Human vs. animal



⇒ ***Human excrements contributed to high nutrient content of Terra Preta***

Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

Bile acids: Human vs. Animal (NDE)



⇒ ***Excrements from pigs and cows contributed to high nutrient content of Nordic Dark Earth***

Wiedner et al. (2015) Catena 132: 114 - 125

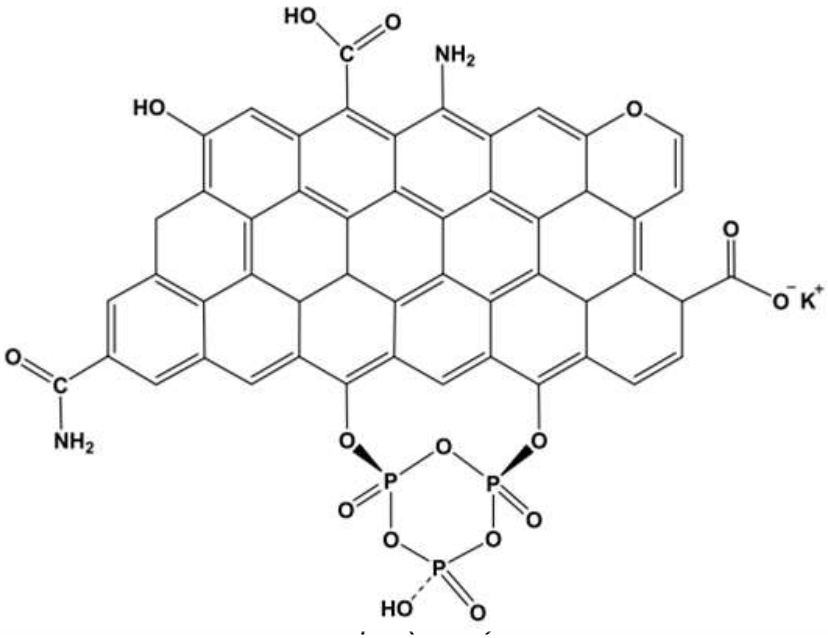
Residues of incomplete combustion (biochar)

Structure

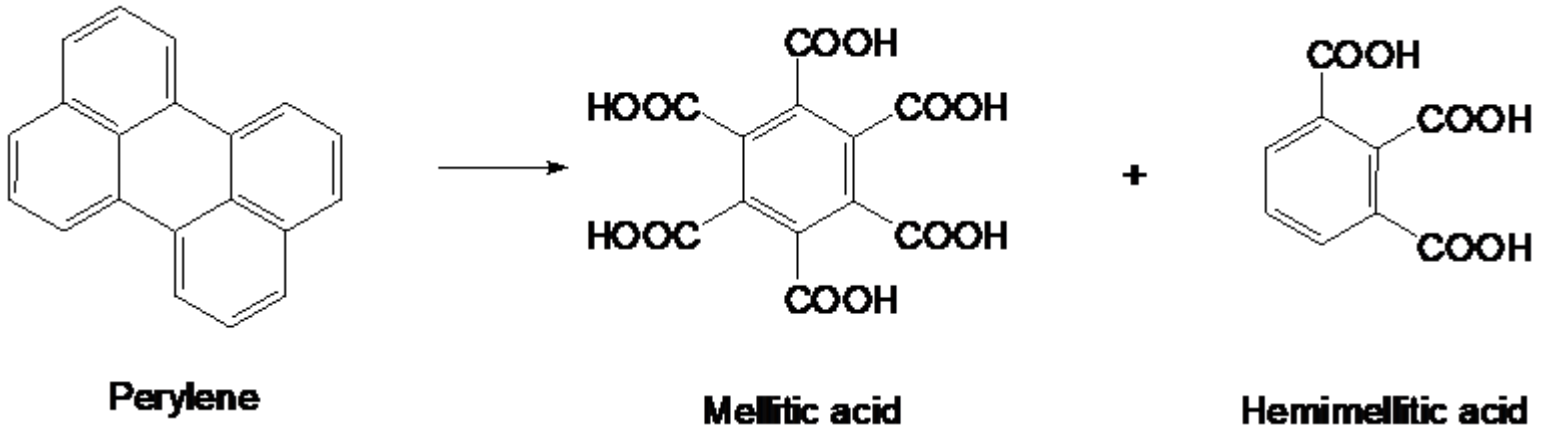
Porosity
Condensed aromatics
Functional groups
Labile organic carbon
Ash

Ecosystem function

⇒ Water storage
⇒ C storage
⇒ Nutrient storage
⇒ Food for microbes
⇒ Immediate fertilizer

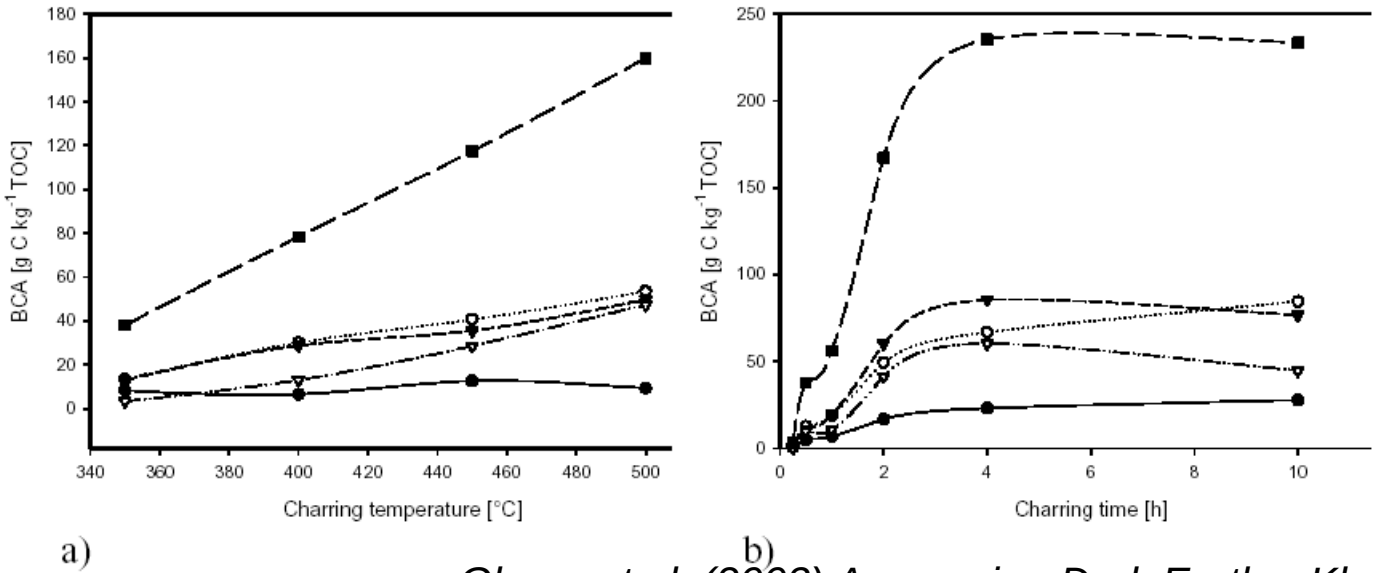


Molecular markers: BPCA



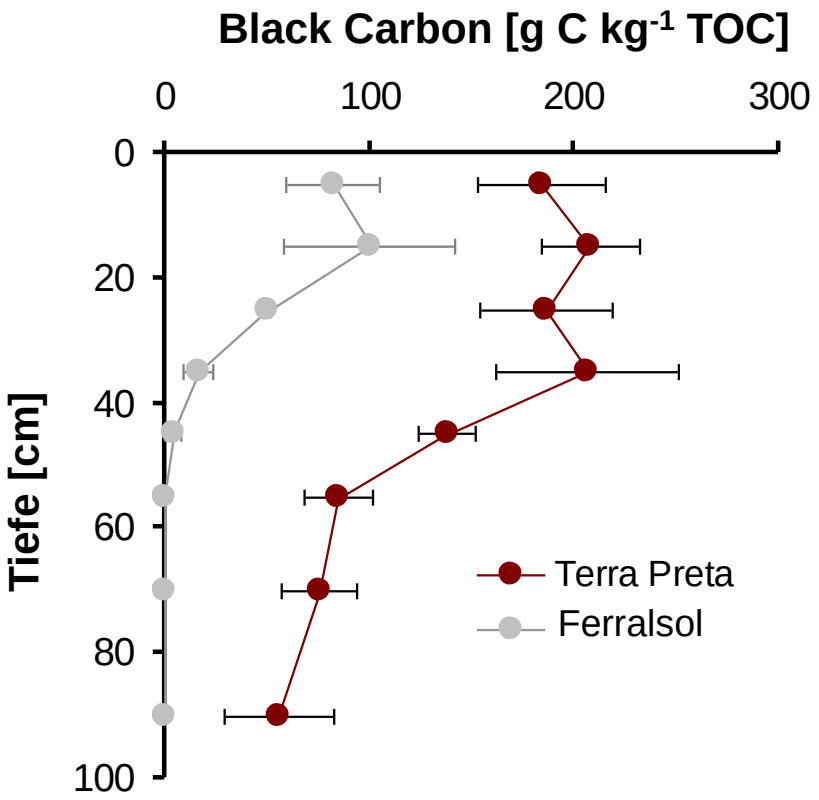
Perylene **Mellitic acid** **Hemimellitic acid**

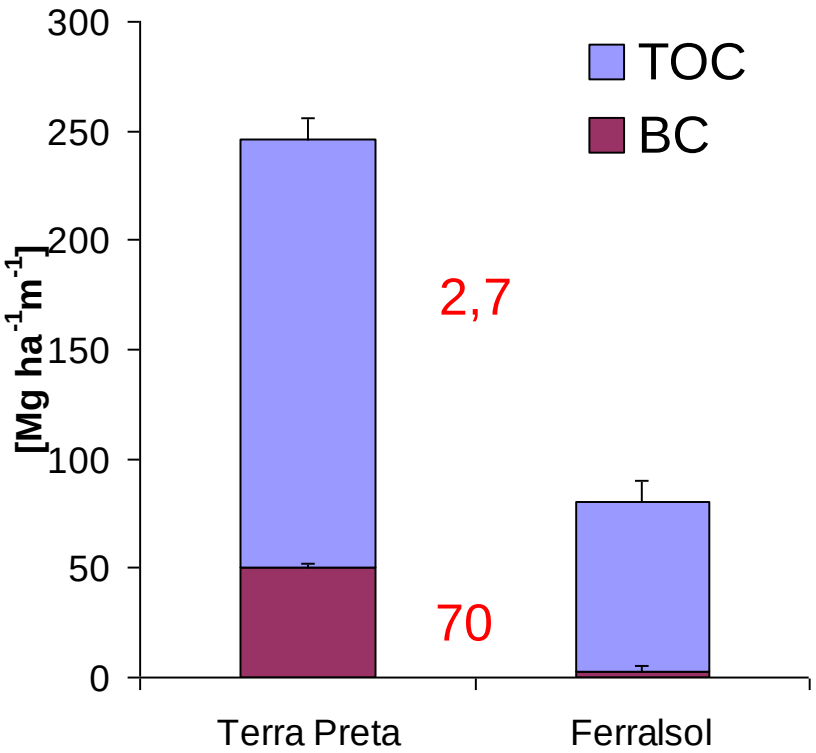
Glaser et al. (1998) Org. Geochem. 29: 811-819



Glaser et al. (2003) Amazonian Dark Earths, Kluwer 227-241

Black Carbon - Biochar



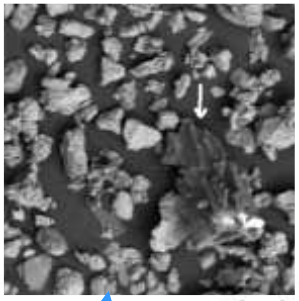


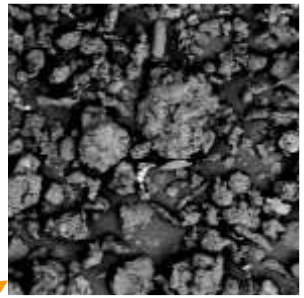
⇒ ***Black Carbon is key component of Terra Preta genesis***

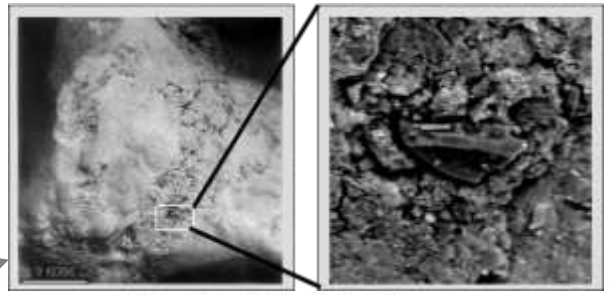
⇒ ***On average 50 Mg ha^{-1}***

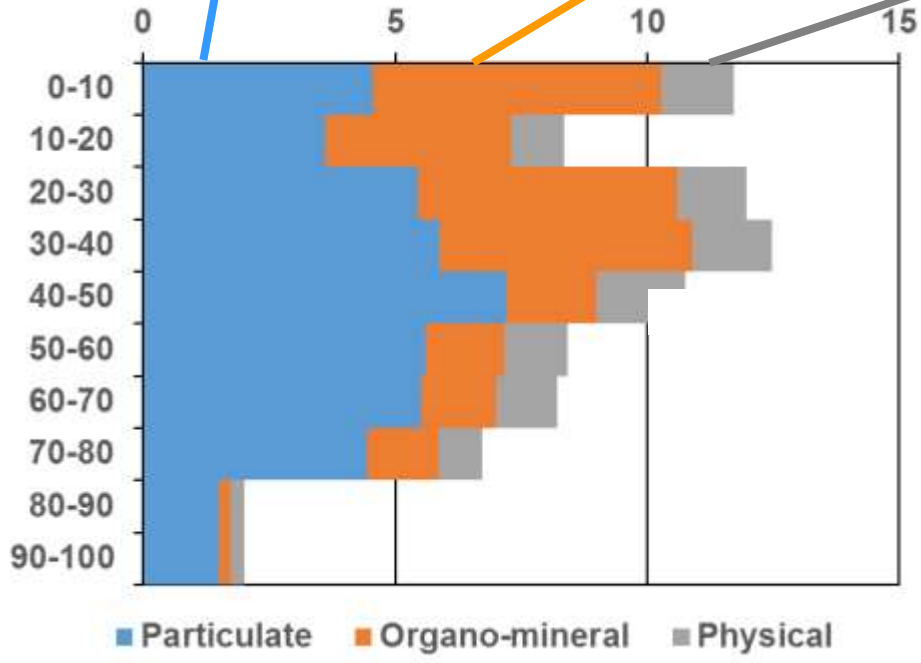
Glaser et al. (2001) Naturwissenschaften 88: 37–41

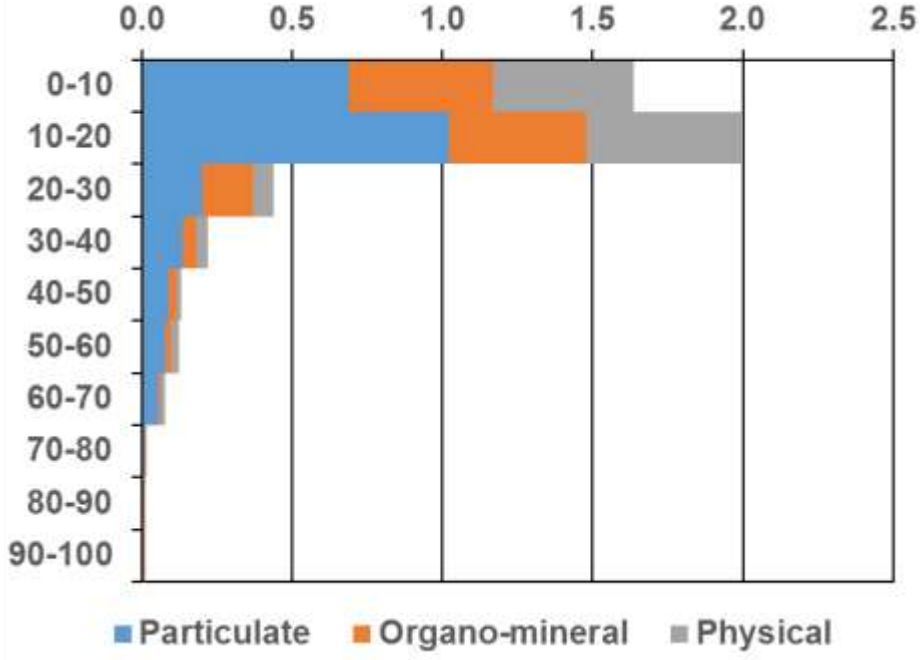
Black carbon stability vs. reactivity







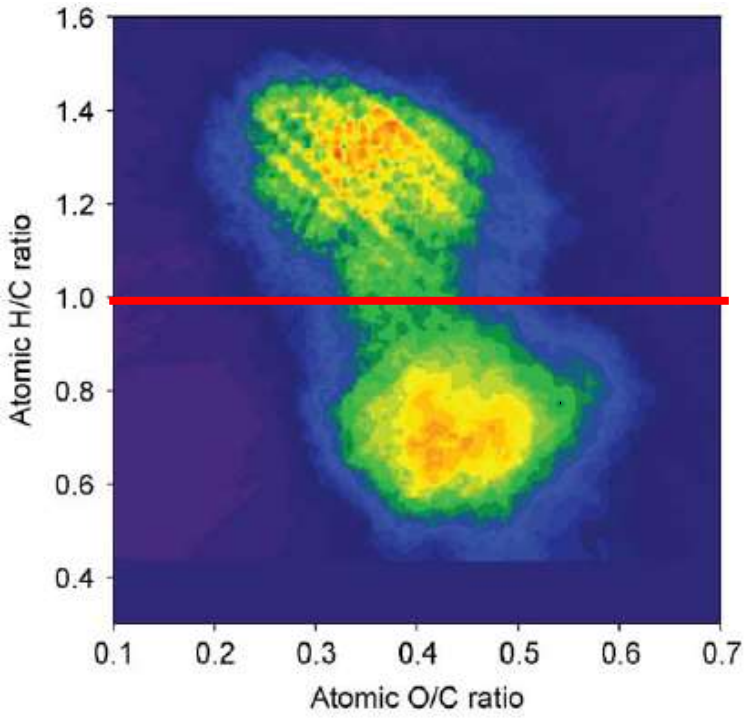




⇒ Low reactivity = stability !!!

Glaser, B. (2014). Soil Biogeochemistry: From molecular to ecosystem level using Terra Preta as example. *In "Agroecology within global environmental changes - Concepts and applications" (N. Benkeblia, M. Lesueur-Jannoyer and H. Ozier-Lafontaine, eds.), pp. 1 – 39. CRC Press, Boca Raton, Florida.*

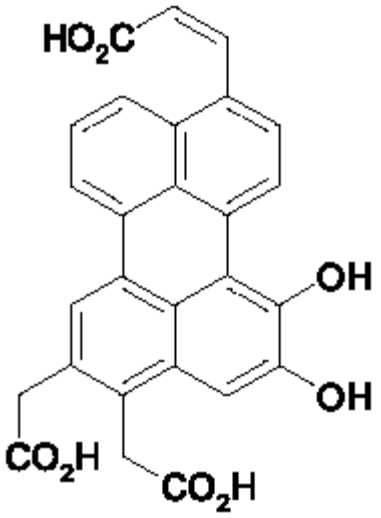
Degradation / metabolites



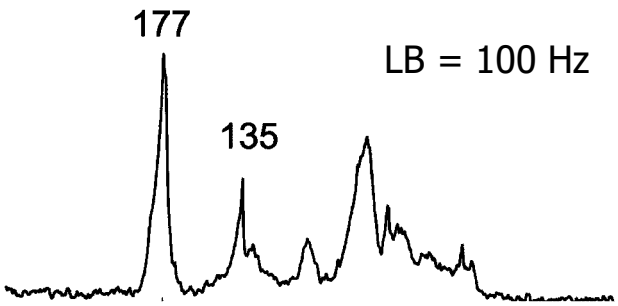
Cellulose

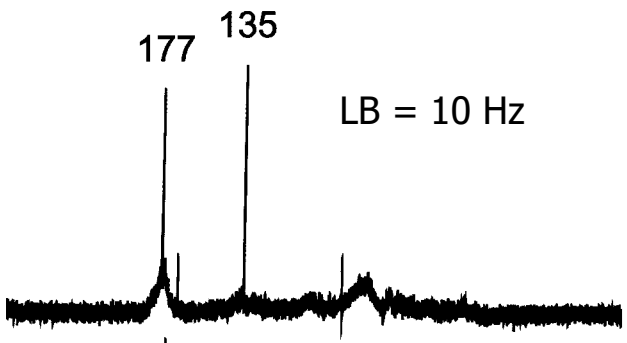
Lignin

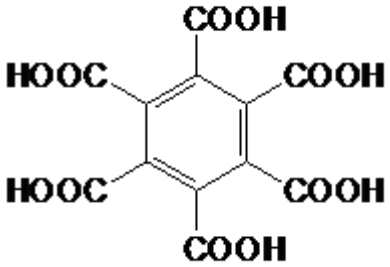
BC



Kim et al (2004) Mar. Chem. 92: 225–234

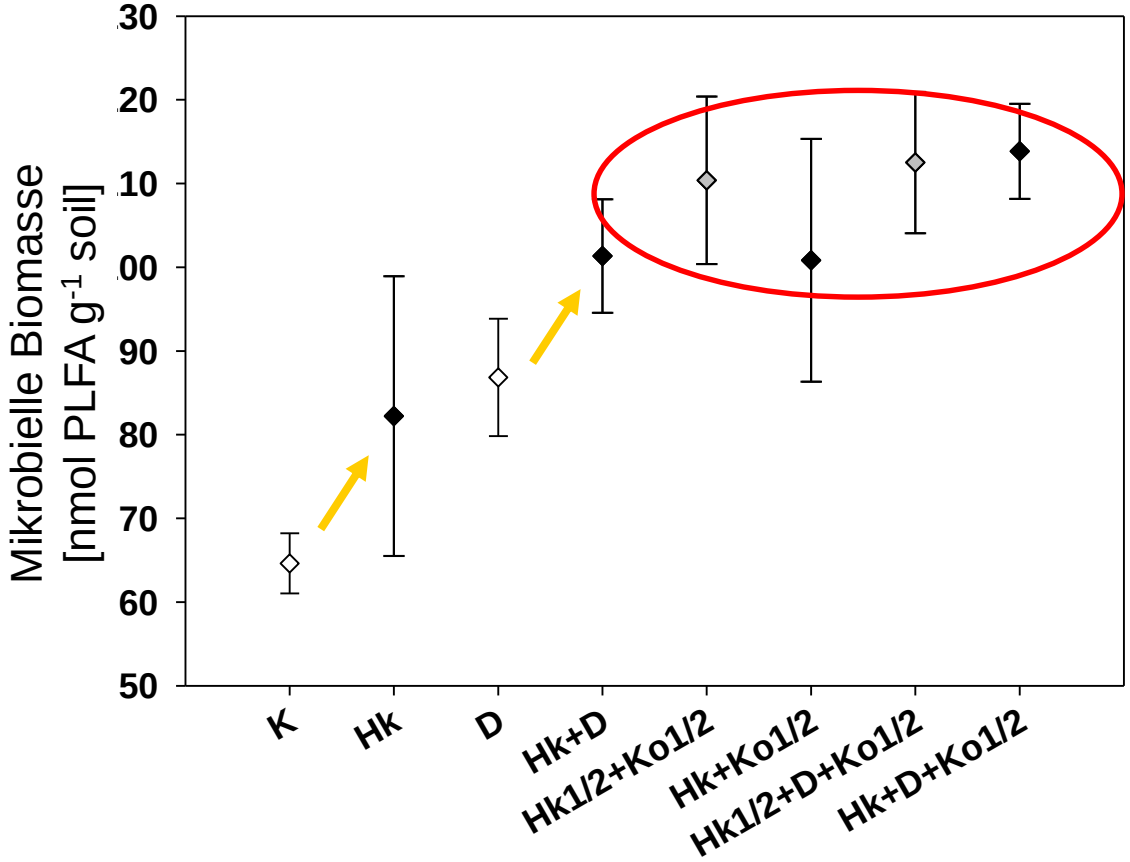






Möller et al (2000) Aust. J. Soil Res. 38: 1017–1035

Role of microorganisms



K : Kontrolle

Ko: Kompost

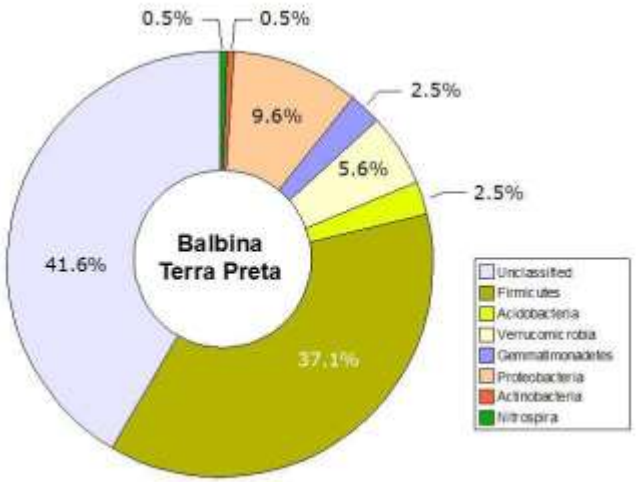
D: Mineraldünger + Kalk

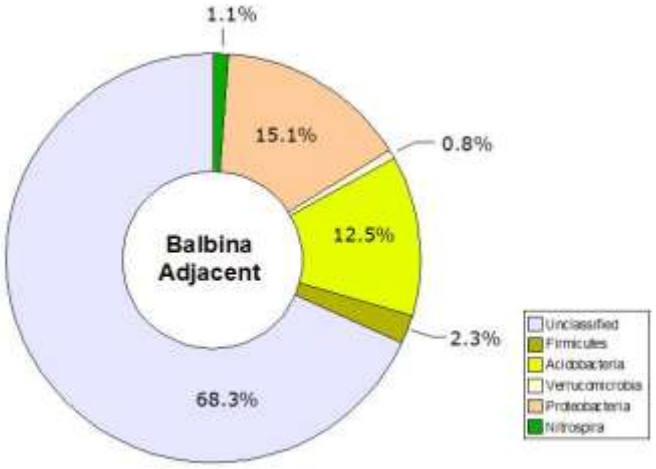
Hk : Pflanzenkohle

⇒ ***Higher microbial biomass in presence of biochar***

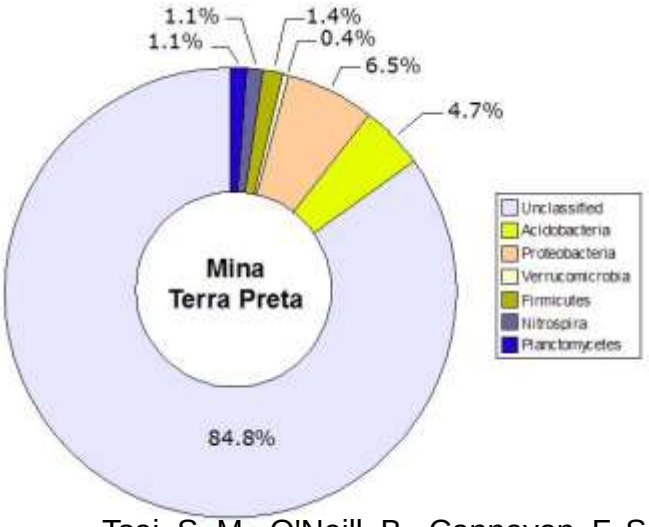
Birk, J. J., Steiner, C., Teixiera, W. C., Zech, W., and Glaser, B. (2009). Microbial Response to Charcoal Amendments and Fertilization of a Highly Weathered Tropical Soil *In "Amazonian Dark Earths: Wim Sombroek's Vision" (W. I. Woods, W. G. Teixeira, J. Lehmann, C. Steiner, A. WinklerPrins and L. Rebellato, eds.), pp. 309-324. Springer.*

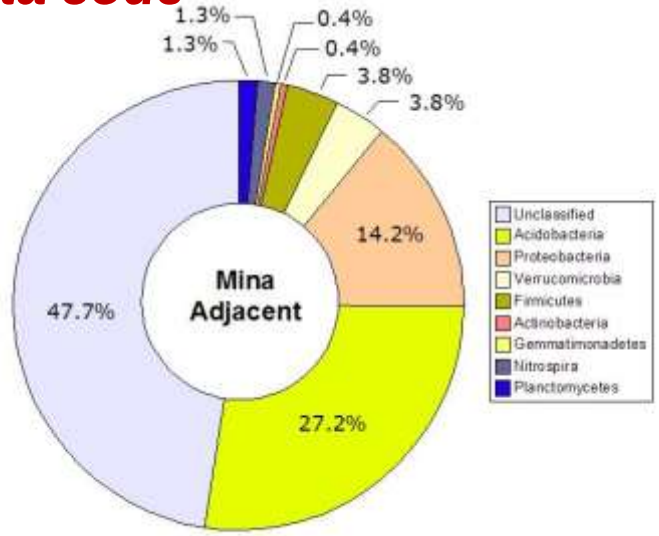
Role of microorganisms





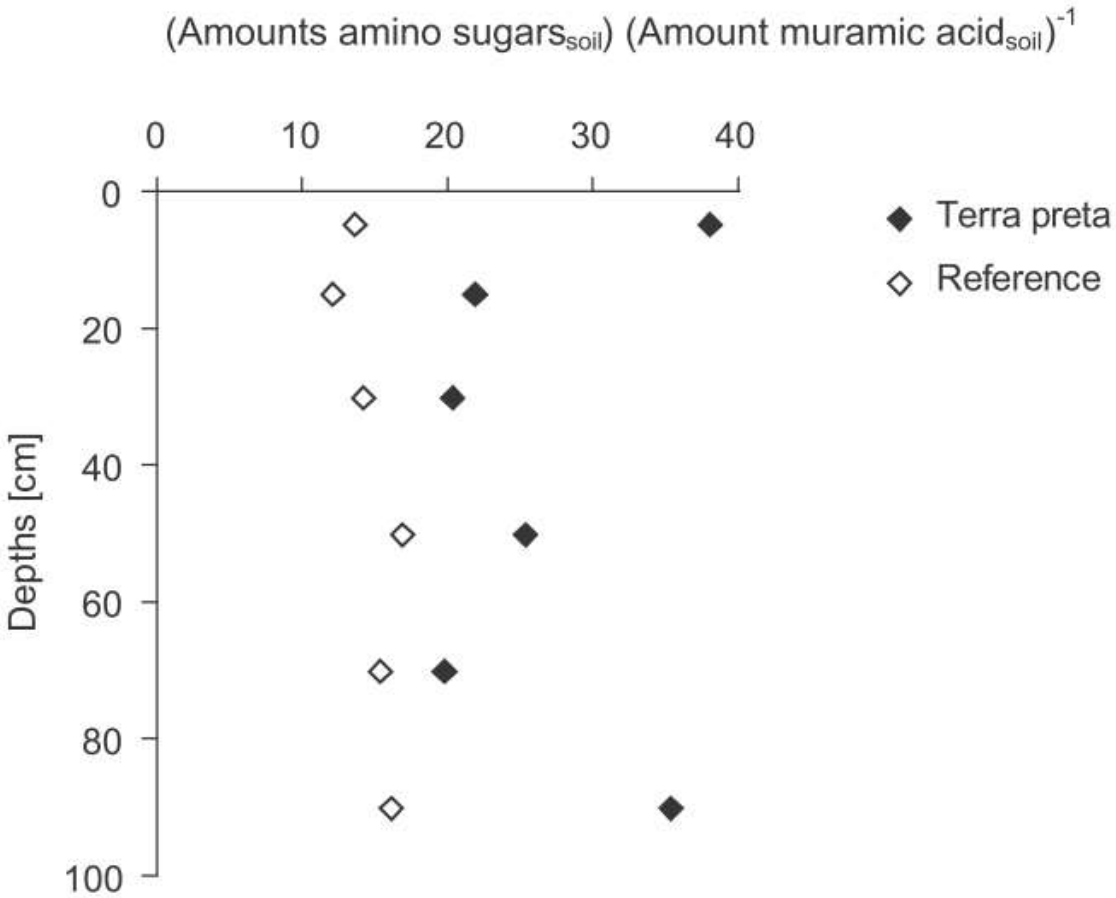
⇒ There is no „Terra Preta code“





Tsai, S. M., O'Neill, B., Cannavan, F. S., Saito, D., Falcao, N. P. S., Kern, D. C., Grossman, J., and Thies, J. (2009). The microbial World of Terra Preta. *In "Amazonian Dark Earths: Wim Sombroek's Vision" (W. I. Woods, W. G. Teixeira, J. Lehmann, C. Steiner, A. WinklerPrins and L. Rebellato, eds.), pp. 299-308. Springer, Heidelberg.*

Fungi vs. bacteria

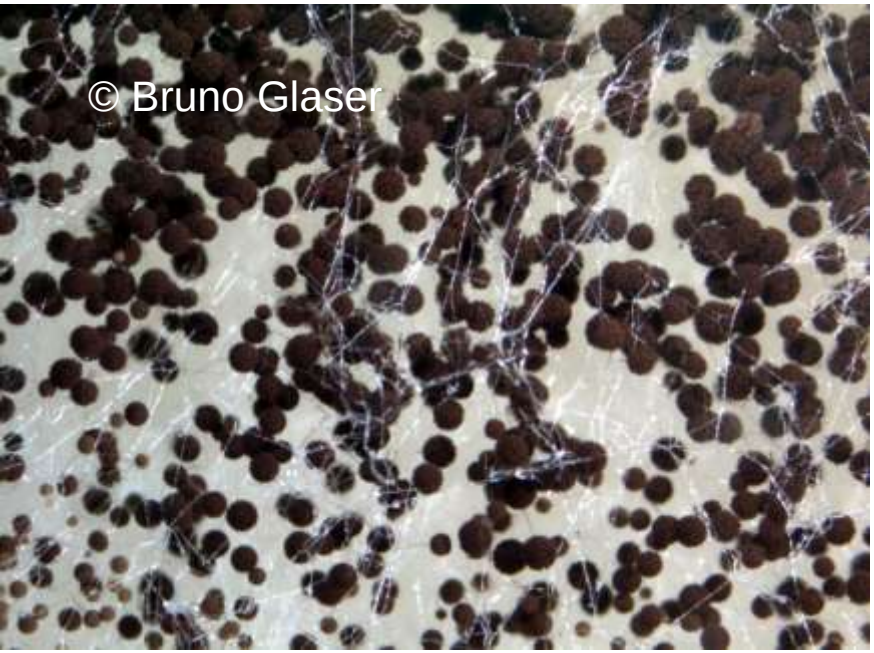


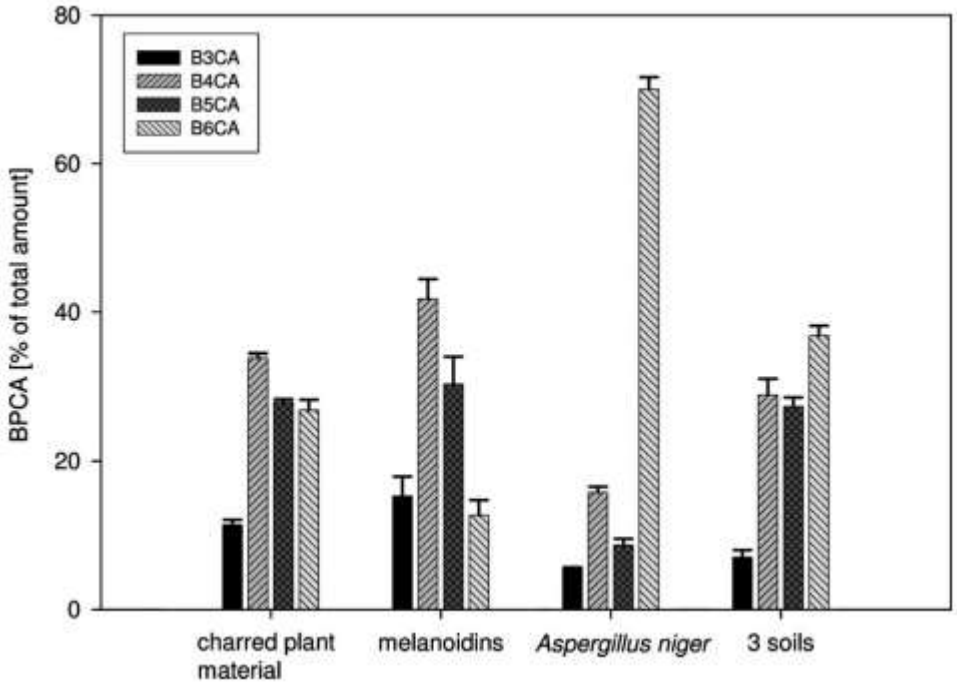
Bacteria ⟷ **Saprophytic fungi**

⇨ ***Terra preta supports saprophytic fungi***

Glaser and Birk (2012) Geochimica et Cosmochimica Acta 82: 39-51

Aspergillus niger

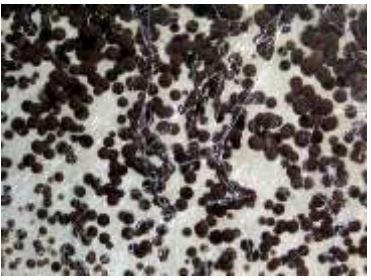


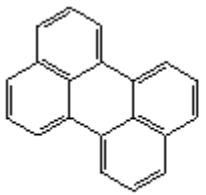


⇒ ***Black pigment***
⇒ ***Structure similar to black carbon***
⇒ ***Dominance of mellitic acid (B6CA)***

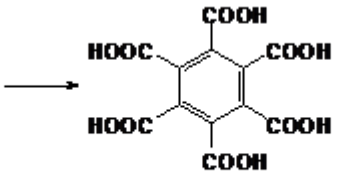
Brodowski et al (2005) Org Geochem 36: 1299-1310

Biological black carbon production

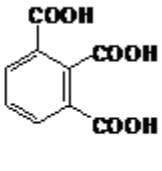




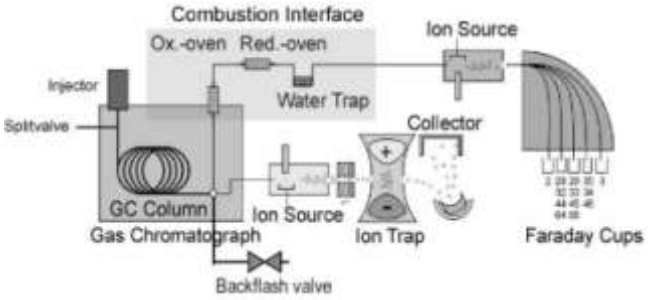
Perylene



Mellitic acid



Hemimellitic acid

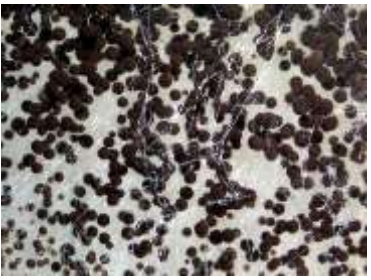


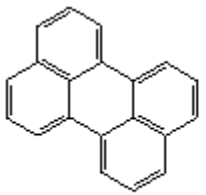
Experiment	Location	Climate	^{13}C tracer	Duration [a]
^{13}C glucose incubation	Laboratory	Temperate	+	1/12
Terra Preta Nova	Brazil	Tropical	+	1
FACE	Switzerland	Temperate	-	7
Eternal maize	Germany	Temperate	+	23

⇒ ***^{13}C labelling (+/- tracer)***
⇒ ***Incubation (1 month up to 23 years)***
⇒ ***Compound-specific stable isotope analysis (BPCA)***
⇒ ***Important: No burning during studies !!!***

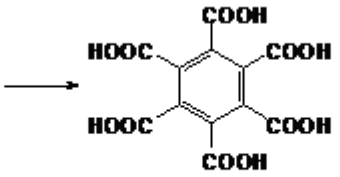
Glaser and Knorr (2008) RCM 22: 935-942

Biological black carbon production

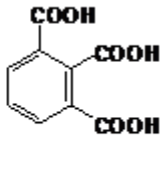




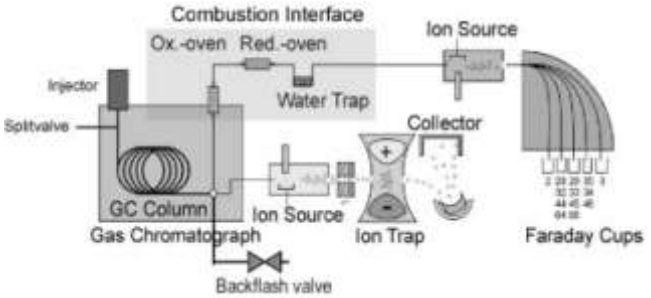
Perylene



Mellitic acid



Hemimellitic acid

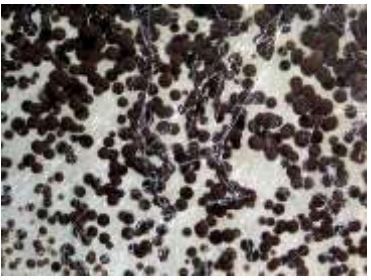


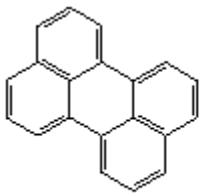
Experiment	Location	Climate	^{13}C tracer	Duration [a]	Bio-BC total	Bio-BC p.a.	BC conc
^{13}C glucose incubation	Laboratory	Temperate	+	1/12	0.001%	0.01%	-22%
Terra Preta Nova	Brazil	Tropical	+	1	9%	9%	-1%
FACE	Switzerland	Temperate	-	7	21%	3%	2%
Eternal maize	Germany	Temperate	+	23	25%	1%	27%

⇒ ***Significant biological BC production !!!***

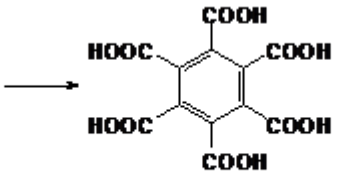
Glaser and Knorr (2008) RCM 22: 935-942

Biological black carbon production

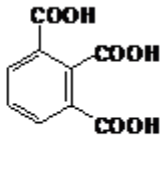




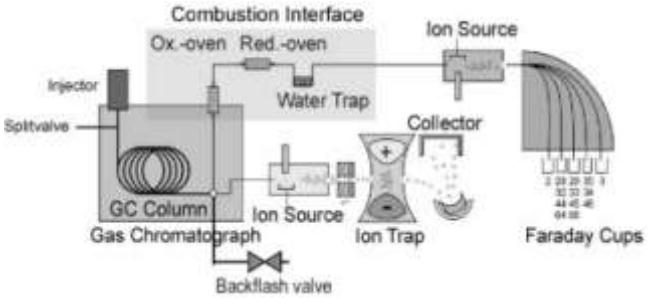
Perylene



Mellitic acid



Hemimellitic acid



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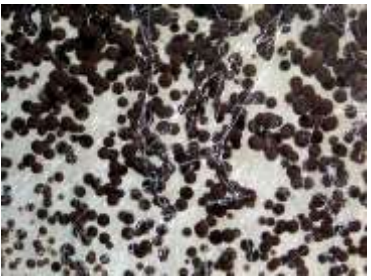
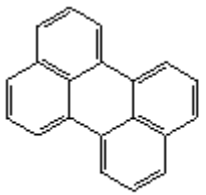
⇒ ***Significant biological BC production !!!***

⇒ $BC_{biological} = f(time)$

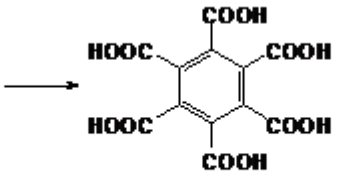
Glaser and Knorr (2008) RCM 22: 935-942

Biological black carbon production

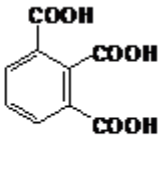




Perylene



Mellitic acid



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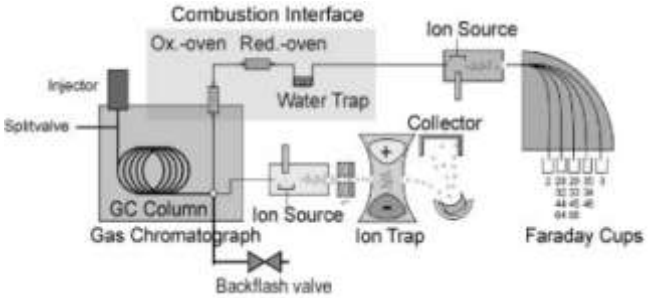

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⇒ ***Significant biological BC production !!!***

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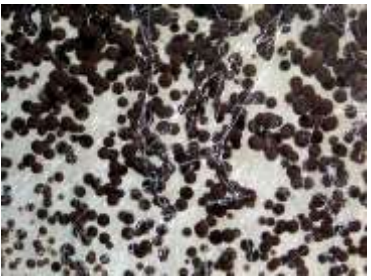
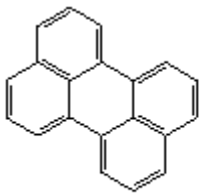
⇒ $BC_{biological} = f(climate)$

Glaser and Knorr (2008) RCM 22: 935-942

Biological black carbon production





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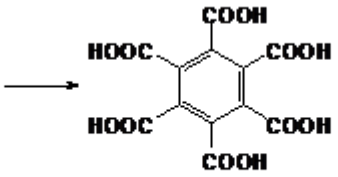

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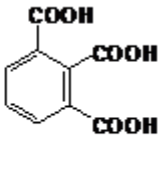

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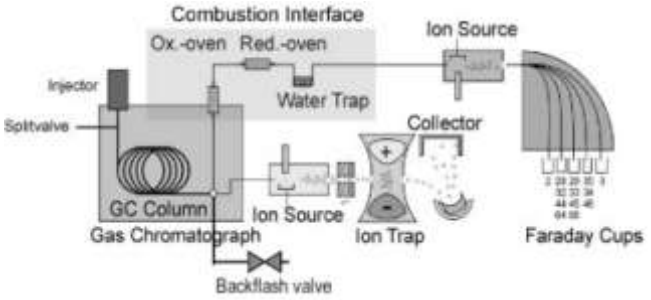

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⇒ ***Significant biological BC production !!!***

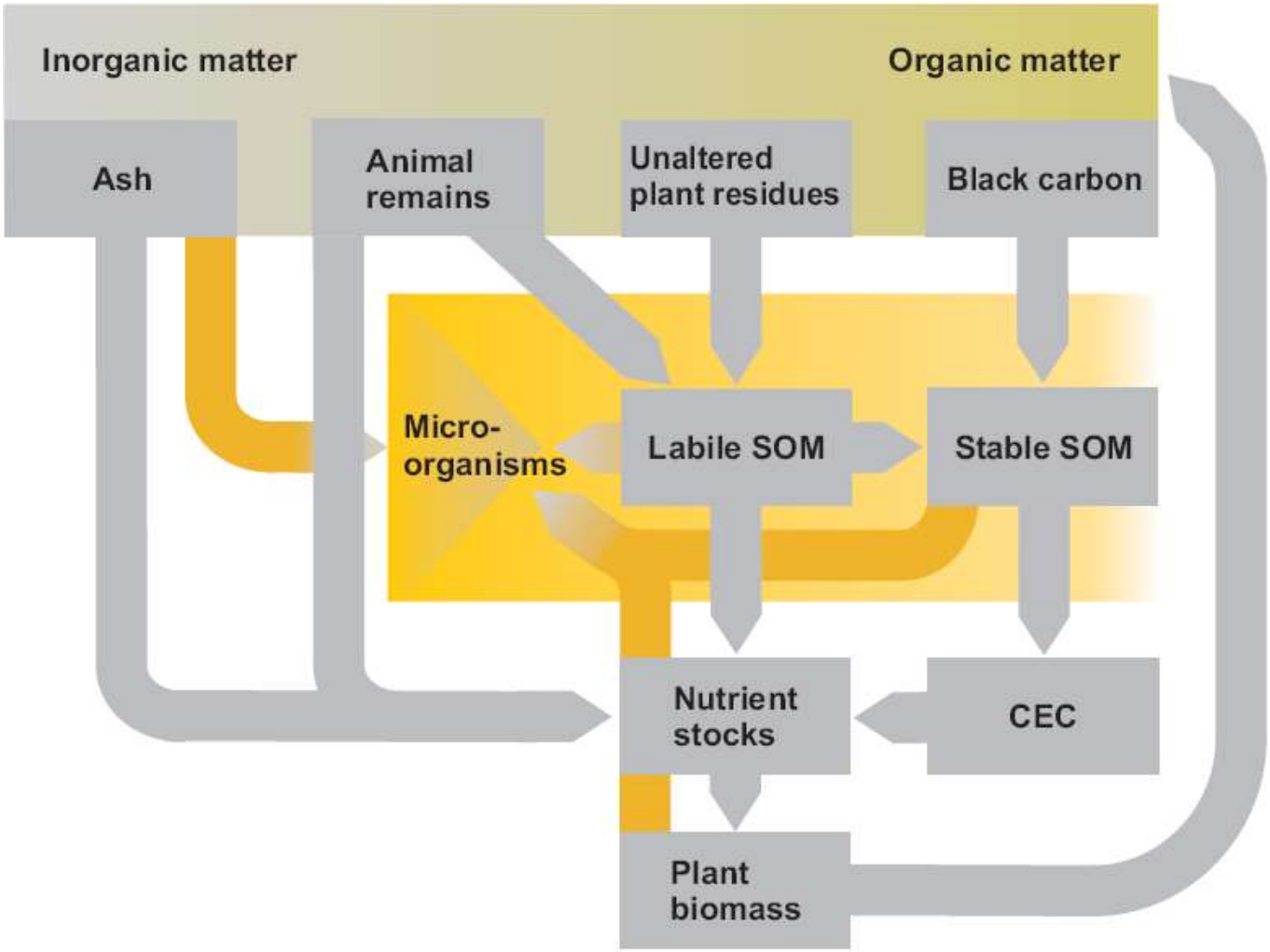
⇒ $BC_{biological} = f(time)$

⇒ $BC_{biological} = f(climate)$

⇒ $BC_{biological} \neq f(BC\ concentration)$

Glaser and Knorr (2008) RCM 22: 935-942

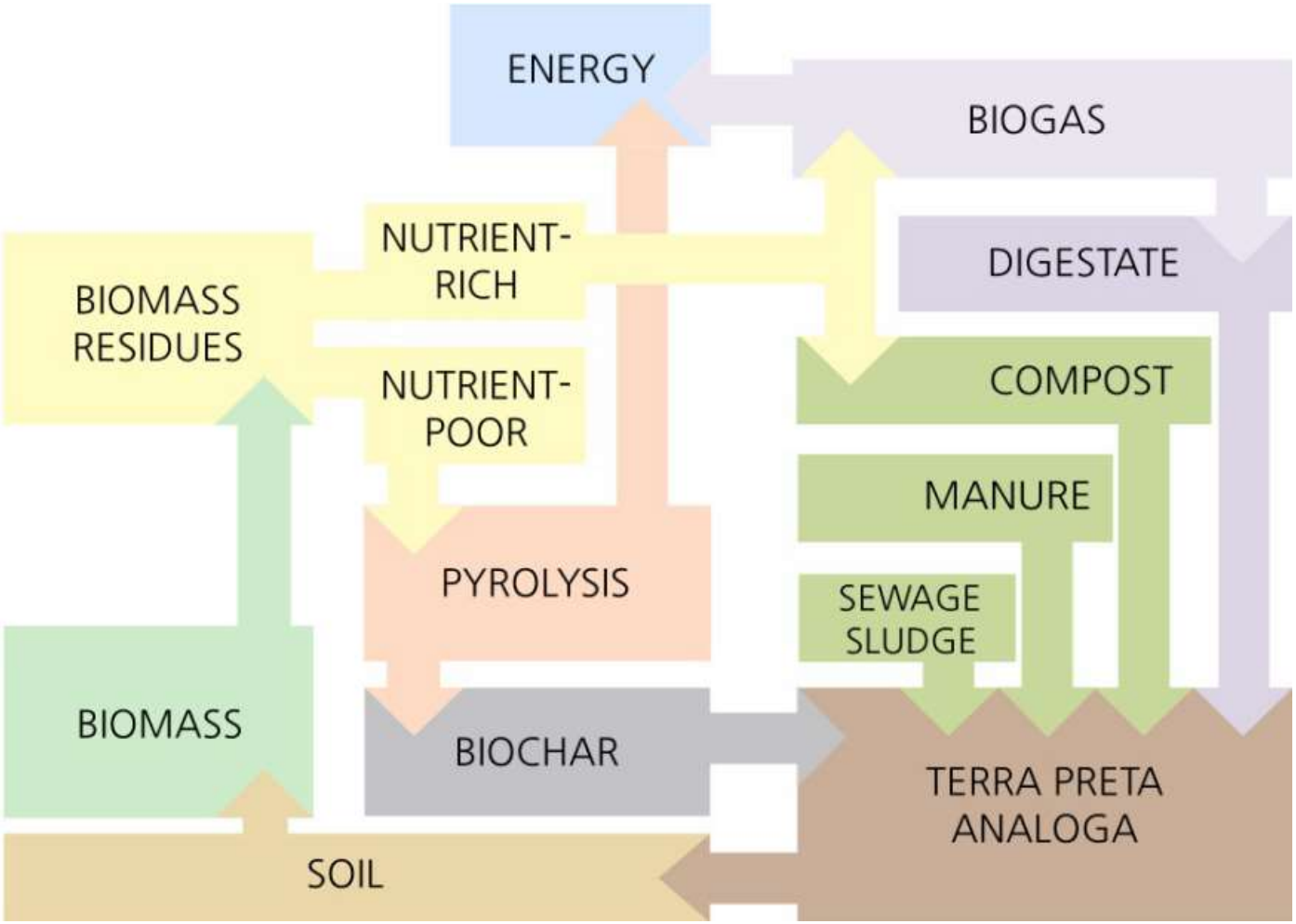
The secret of Terra Preta



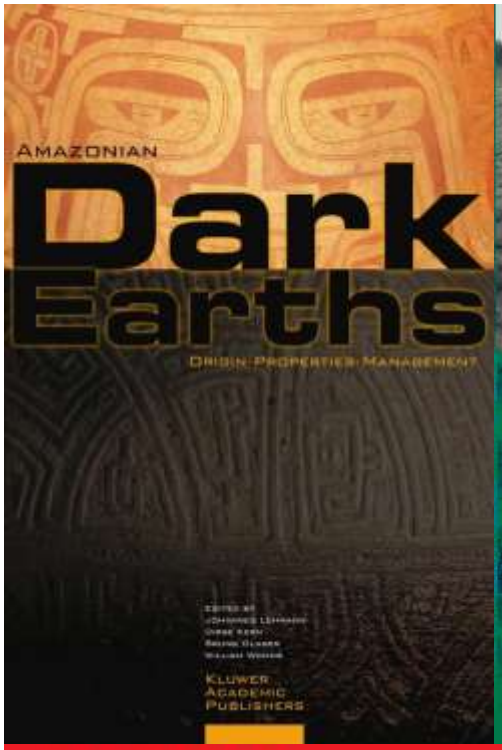
⇒ Bio-based circular economy

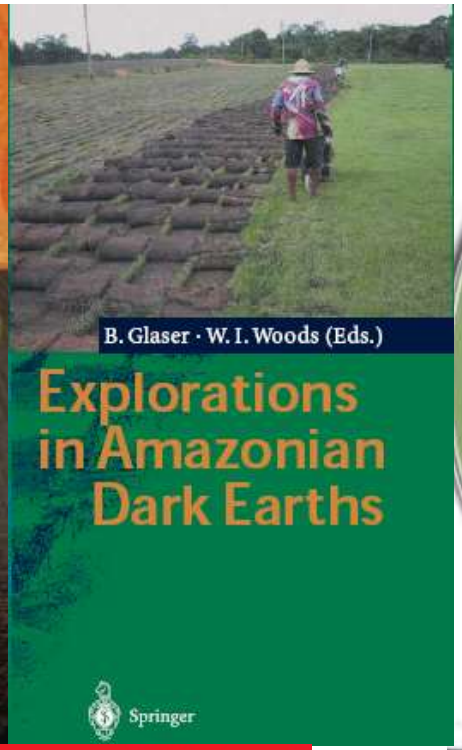
Glaser and Birk (2012) Geochim. Cosmochim. Acta 82: 39–51

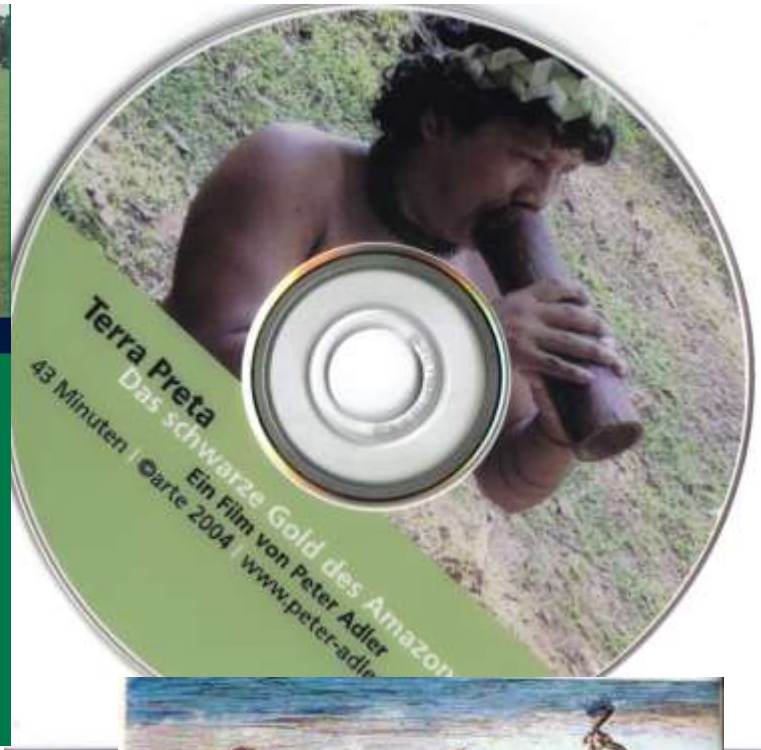
Modern Terra Preta concept



Further reading / watching







Drop of the black stuff: terra preta contrasts strongly with normal soil in colour (left) and produces much more vigorous crops (below).

middens of settlements and are cluttered with crescents of broken pottery. The larger patches were once agricultural areas that the farmers enriched with charred trash of all sorts. Some soils are thought to be 7,000 years old. Compared with the surrounding soil, *terra preta* can contain three times as much phosphorus and nitrogen. And as its colour indicates, it contains far more carbon. In samples taken in Brazil by William Woods, an expert in abandoned settlements at the University of Kansas in Lawrence, the *terra preta* was up to 9% carbon, compared with 0.5% for plain soil from places nearby[1].

From Smith's time onwards, the sparse scholarly discussion of *terra preta* was focused mainly on the question of whether 'savages' could have been so clever as to enhance their land's fertility. But Woods' comprehensive bibliography on the subject now doubles in size every decade. About 40% of the papers it contains were published in the past six years.

Black is the new green

Indianer bei der Feldarbeit (Kupferstich, 16. Jahrhundert)
Fruchtbarer Boden durch Holzkohle und Gräten

Working in the humid tropics