Urban Soils and Carbon Sequestration

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Overview

- Urbanization
- Research on Urban Soils
- Technosols
- Properties of Urban Soils
- Soil Carbon Sequestration
- Organic Carbon Storage in Urban Forest Soils
- Conclusions

Introduction

>50% of the Global Population Lives in Cities

☞ Projected to increase strongly (UNFPA, 2007)

Urban Land Cover

1700: 0.01% Global Ice-free Land Area

2002: 0.50% (Schneider et al., 2009)

Urban Lands

Among Most Intensively Transformed Lands (Ellis et al., 2010)

Urbanization

☞Primary Process of Land Cover Transformation (Pavao-Zuckerman and Byrne, 2009)

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Urbanization

Expansion of Urban Land Uses, Including Commercial, Industrial, and Residential Uses

- ➢ **Global Human Alteration of Ecosystems (Grimm et al., 2008)**
- ➢ **On Earth's Most Fertile Lands (Seto and Sheperd, 2009)**
  - ☞ **Urban Areas Require Agricultural Production in Other Areas, and Resources such as Water, Energy and Transportation Infrastructure**

Urbanization

Area of the Size of California will be Converted Globally to Urban Areas by 2030 (Angel et al., 2005)

Impervious Surface Area in the USA approaches the Size of Ohio (Elvidge et al., 2004)

Urban Sprawl (i.e., the Spreading of a City Into Rural Land)

☞ **Directly affects a Quarter of the Territory of the European Union (European Environment Agency, 2006)**

Urbanization

- Studies on Urban Ecosystems have been traditionally neglected by Ecologists and Soil Scientists (Grimm et al., 2008),

  e.g., Urban Long-term Ecological Research (LTER) sites are studied only for a Decade in Baltimore and Phoenix,

  but are missing in many other cities such as those in Europe (Shochat et al., 2006; Pickett et al., 2008; Metzger et al., 2010)

- Little is known about the Effects of Increasing Urban Land Use on the Ecology of Soils (Byrne, 2007)

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History Urban Soil Science

(modified from Lehmann and Stahr, 2007)

1847	**Soil Science Textbook** by Ferdinand Senft: Soils in **Urban**, Industrial and Mining Environments with Little Fertility due to Deposited Toxic Wastes
1951	**Mapping Urban Soil Types** in Bottrop, Germany, by Mückenhausen and Müller
1963	Chemical and Physical properties of Soils from Moscow, Russia, described by Zemlyanitskiy
1982	**International Symposium on Urban Soils** in Berlin, Germany
1991	First Pedological Compendium on Urban Soils by Bullock and Gregory
1995	International Committee on Anthropogenic Soils (ICOMANTH): Proposal to Address Anthropogenic Soils in NRCS Soil Taxonomy
1997	Field Manual for Describing Anthropogenic Urban Soils by German Soil Science Society Baltimore Ecosystem Study and Central Arizona - Phoenix LTER sites
1998	International Union of Soil Sciences Working Group: Urban Soils – **Soils of Urban, Industrial, Traffic, Mining, and Military Areas (SUITMA)**
2000	1st SUITMA Conference Essen, Germany
2005	Urban Soil Primer by NRCS
2006	**World Reference Base (WRB)** for Soil Resources: Anthropogenic Urban Soils within the Soil Group **Technosols** (updated 2007)
2009	5th SUITMA Conference, New York City, USA
2011	*6th SUITMA Conference, Marrakech, Morocco*

Technosols
(IUSS Working Group WRB, 2007)

One of the 32 Reference Soil Groups

- ☞ Properties and pedogenesis dominated by ***technical*** origin
- ☞ Significant amount of ***artefacts*** (something in the soil recognizably made or extracted from the earth by humans), or sealed by ***technic hard rock*** (hard material created by humans, having properties unlike natural rock)
- ☞ (i) soils from wastes (landfills, sludge, cinders, mine spoils and ashes),

  (ii) pavements with their underlying unconsolidated materials,

  (iii) soils with geomembranes and constructed soils in human-made materials

Technosols are often referred to as ***urban*** or ***mine*** **soils**

Technosols
(IUSS Working Group WRB, 2007)

***Parent material*:** Materials made or exposed by human activity otherwise would not occur at the Earth's surface; pedogenesis affected strongly by materials and their organization

***Environment*:** Mostly in urban and industrial areas, in small areas associated with other groups

***Profile development*:** Generally none, although in old dumps (e.g., Roman rubble) evidence of *natural* pedogenesis can be observed, such as clay translocation. Lignite and fly ash deposits may exhibit over time *vitric* or *andic* properties. Original profile development may still be present in contaminated natural soils

Technosols
(IUSS Working Group WRB, 2007)

Global distribution where human activity has led to

(i) the construction of artificial soil,

(ii) sealing of natural soil, or

(iii) extraction of material normally not affected by surface processes

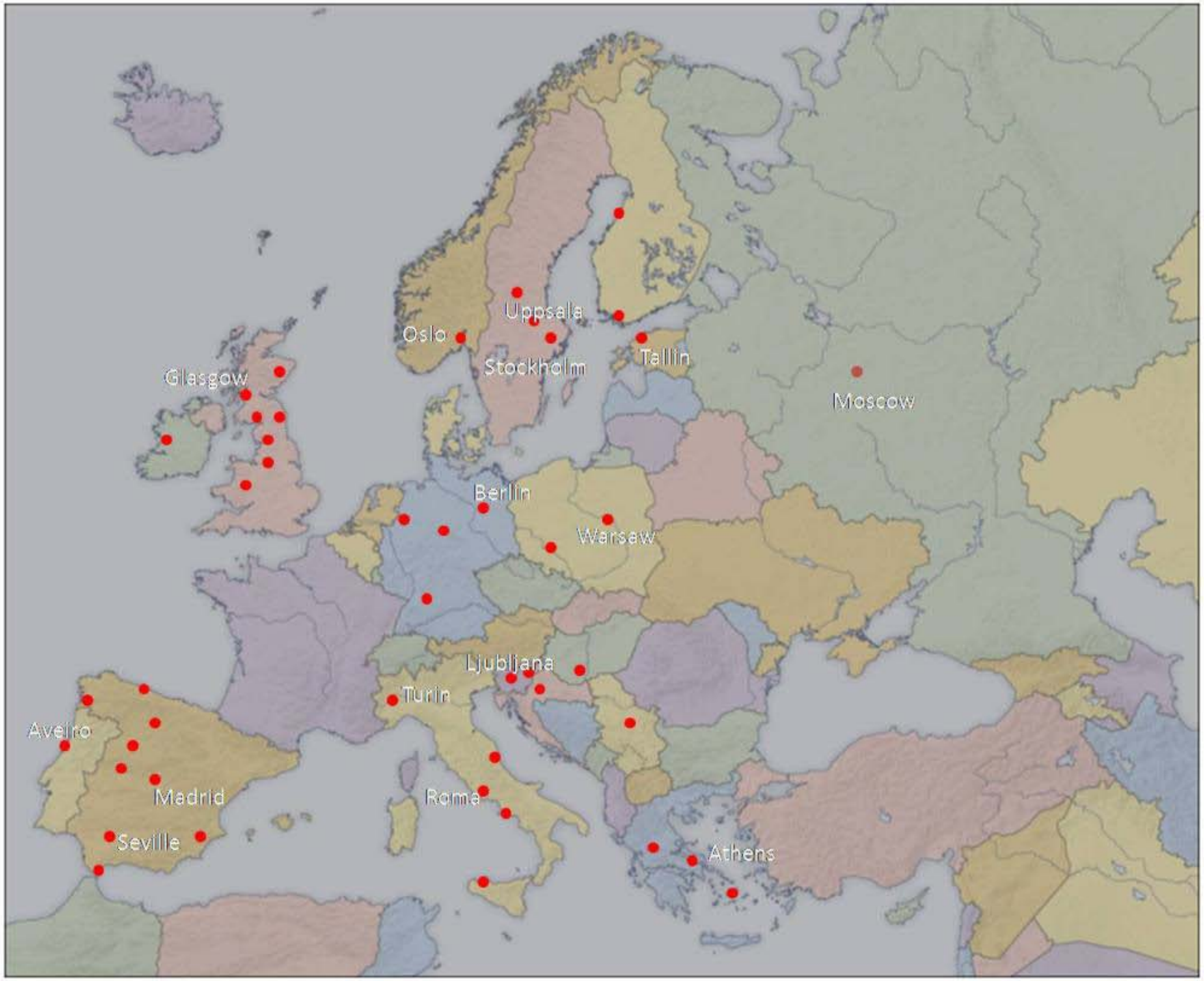
☞ **Cities**, **roads**, mines, refuse dumps, oil spills, coal fly ash deposits etc.

Management and Use

Affected strongly by the nature of the material or the human activity - more likely to be contaminated may contain toxic substances resulting from industrial processes.

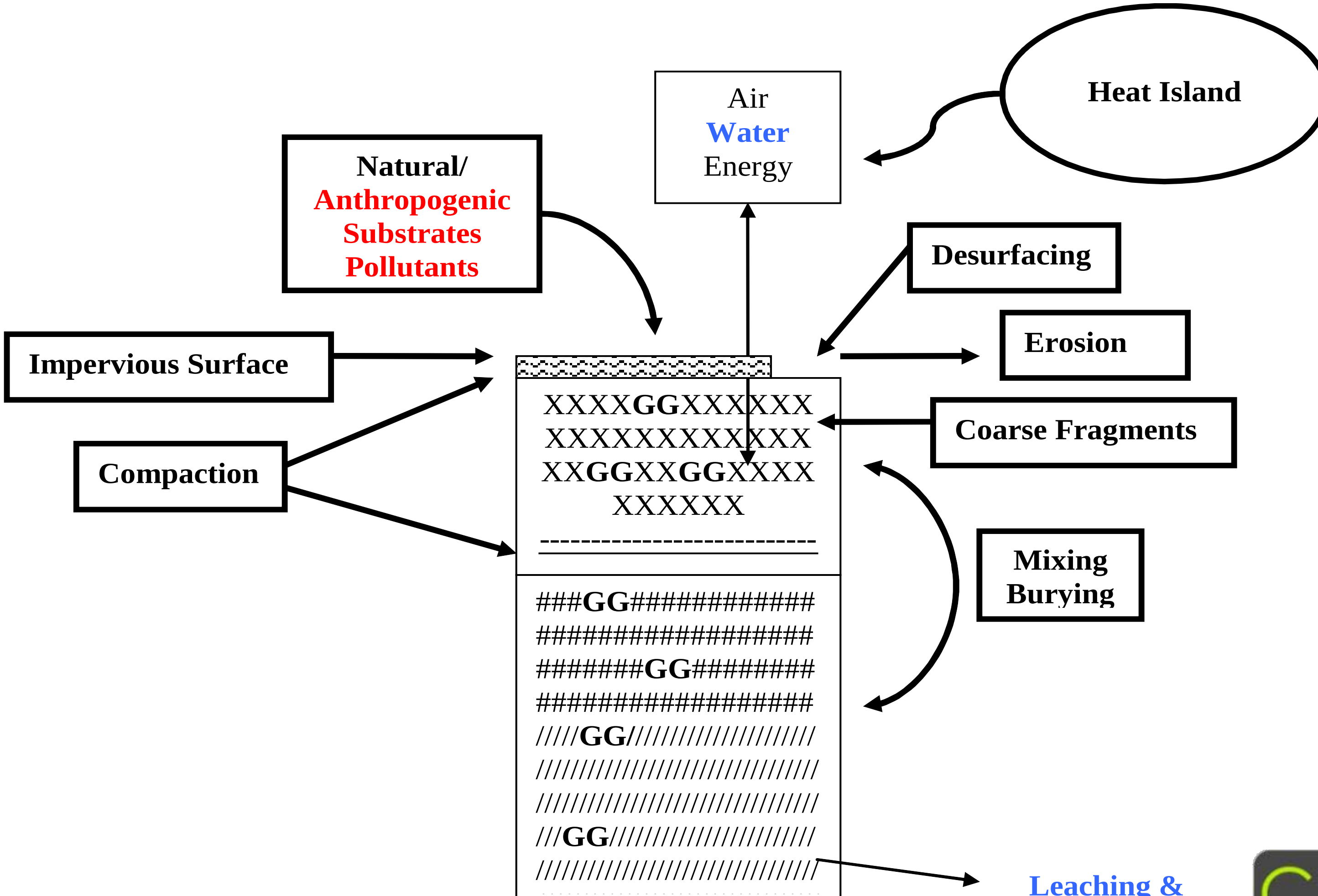
Many Technosols covered with a layer of *natural* soil material in order to permit revegetation.

Mapping Urban Soils
Metal Contamination

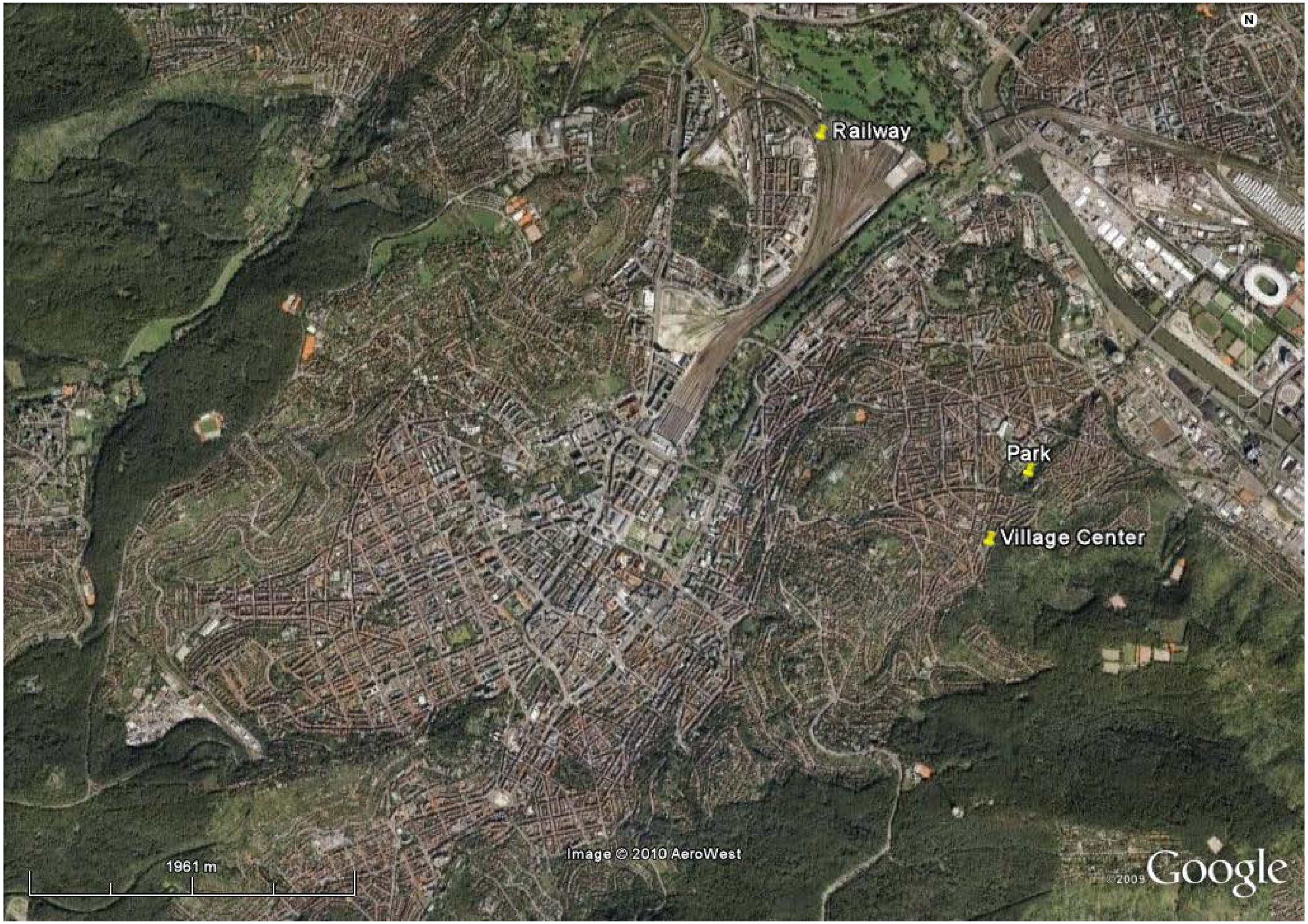


Franco Ajmone-Marsan. 2009. Università di Torino, DIVAPRA - Chimica agraria

Physical Disturbance
Urban Soil Profile



Stuttgart, Germany



Stuttgart, Germany

Railway

- Discontinued for several years
- Anthropogenic substrates
- Patchy vegetation

Village Center

- Fill material added several times containing natural/anthropogenic substrates
- Ruderal vegetation

Park

- Public park since 1960s
- Fill material added from tunnel excavation and WWII
- Lawn, trees, shrubs

Stuttgart, Germany

(WRB Classification, photo credits Andreas Lehmann)

Railway	Village Center	Park
		
Spolic Technosol (Calcaric, Humic, Skeletic)	***Urbic Technosol (Calcaric, Ruptic, Humic, Densic)***	***Urbic Technosol (Humic)***
Anthropogenic substrates	Layers of filled substrates	Loamy layer covering two layers of sandy slag

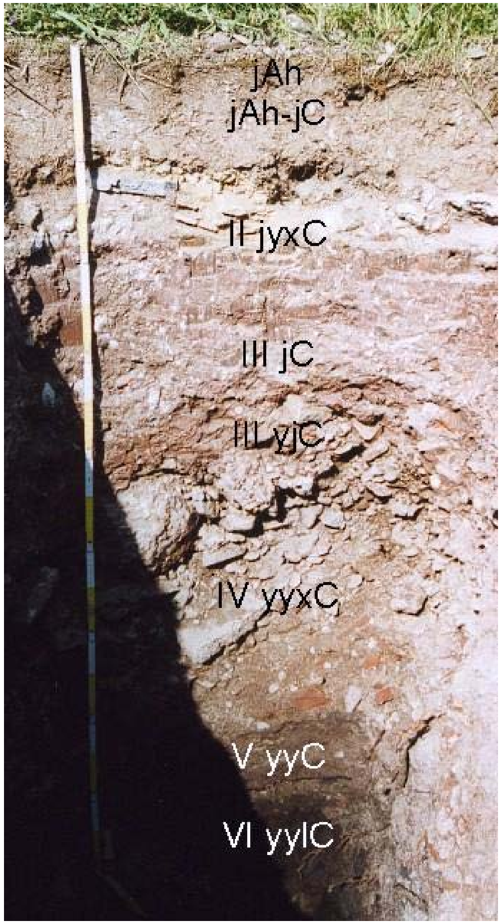
Railway | R

Depth	Sand	Silt	Clay	>2mm	B.D.	SOC	N	C/N	Cd	Cu	Pb	Zn
cm	-------------%-------------				g cm^{-3}	------%-----			------------mg kg^{-1}-----------			
0-8	82	16	2	30	1.2	1.1	0.04	28	0.2	56	30	**145**
8-25	48	31	21	64	n.d.	11.3	0.24	48	0.8	**85**	**171**	**285**
25-50(1)	30	34	36	47	n.d.	3.2	0.09	36	0.2	30	**64**	**142**
25-50(2)	48	32	20	75	n.d.	8.2	0.13	63	0.5	**287**	**180**	**322**
50-78	50	29	21	76	n.d.	13.4	0.28	47	0.4	**112**	297	**290**

Stahr et al. (2003)
red: exceeding background values for rural areas in Baden-Wuerttemberg

Spolic Technosol
(Calcaric, Humic, Skeletic)

Village Center H1



Urbic Technosol (Calcaric, Ruptic, Humic, Densic)

Depth	Sand	Silt	Clay	>2mm	B.D.	SOC	N	C/N	Cd	Cu	Pb	Zn
cm	---------------%---------------				g cm^{-3}	-------%------			----------mg kg^{-1}----------			
0-6	33	42	25	8	0.9	3.7	0.26	14	1.0	46	42	**202**
6-20	33	45	22	24	1.2	2.8	0.19	15	**1.1**	47	41	**200**
20-35	90	7	3	68	0.8	0.2	0.02	9	0.3	20	16	89
35-75	47	31	22	21	1.6	1.1	0.07	16	0.8	**221**	**79**	**524**
75-155	n.d.	n.d.	n.d.	84	1.7	3.1	0.13	24	0.8	**264**	**169**	**608**
155-170	40	39	21	33	1.3	5.3	0.16	33	0.7	**118**	**134**	**327**
170-190	52	32	16	50	1.0	35.9	0.65	55	0.7	44	**86**	**161**

Stahr et al. (2003)

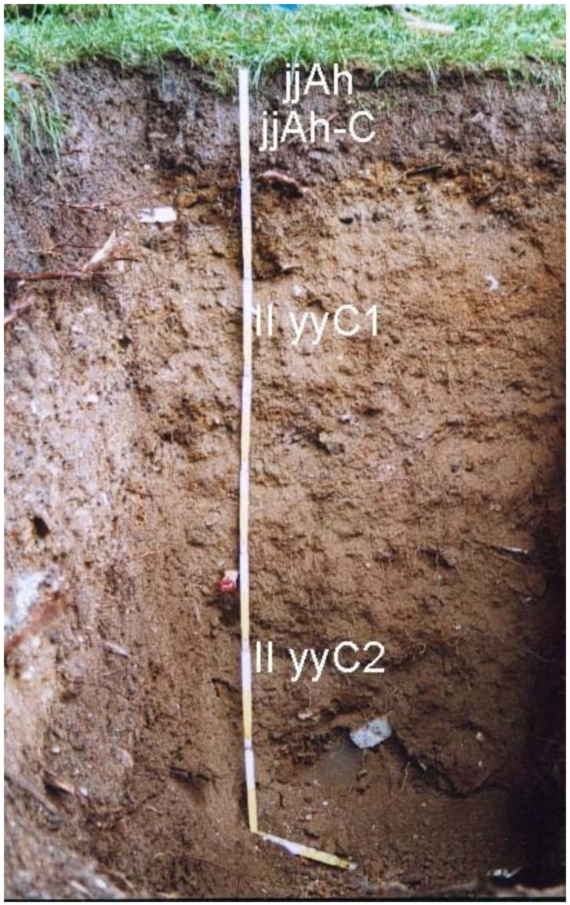
red: exceeding background values for rural areas in Baden-Wuerttemberg

Park | P2

Depth	Sand	Silt	Clay	>2mm	B.D.	SOC	N	C/N	Cd	Cu	Pb	Zn
cm	---------------%----------------				g cm^{-3}	------%-----			-----------mg kg^{-1}----------			
0-5	31	44	25	1	0.9	10.3	0.53	19	0.9	**182**	**313**	**483**
5-25	31	41	28	17	1.3	7.5	0.31	22	0.8	**124**	**248**	**396**
25-80	56	39	5	36	0.7	19.4	0.32	61	**1.7**	**442**	**827**	**1087**
80-160	61	31	8	23	0.7	16.8	0.30	56	**1.6**	**475**	**304**	**623**

Stahr et al. (2003)

red: exceeding background values for rural areas in Baden-Wuerttemberg



Urbic Technosol (Humic)

Soil Properties Rural-Urban Transect Stuttgart, Germany

(modified from Stahr et al., 2003)

Land Use	Depth (cm)	Coarse Fraction (w, g kg^{-1})	Bulk Density (Mg m^{-3})	**Saturated Hydraulic Conductivity (cm d^{-1})**	**Field Capacity (cm^3 cm^{-3})**	**Plant Available Water Capacity (cm)**	**Soil Organic Carbon (%)**
Forest	0-30	68	1.12	1119		1.50	12.2
	30-100	153	1.63	55		3.57	4.1
	0-100				0.27	10.10	
Agriculture	0-30	32	1.47	165		2.22	15.1
	30-100	47	1.59	221		6.93	4.7
	0-100				0.37	17.30	
Vineyard	0-30	313	1.50	3194		0.81	11.0
	30-100	423	1.52	3552		4.69	5.2
	0-100				0.34	9.40	
Park	0-30	106	1.39	1913		1.05	18.6
	30-100	223	1.30	**1100**		**6.37**	**11.6**
	0-100				**0.33**	**12.60**	
Allotment	0-30	333	1.43	988		0.45	22.7
	30-100	198	1.43	588		6.51	10.5
	0-100				0.37	10.80	
House	0-30	83	1.28	1098		1.50	26.2
	30-100	111	1.44	1776		6.93	4.1
	0-100				0.34	14.90	
Village Center	0-30	20	1.54	**43**		**1.26**	**13.4**
	30-100	235	1.60	301		4.69	**4.1**
	0-100				**0.33**	10.90	
City Center	0-30	199	1.43	974		1.11	11.0
	30-100	300	1.63	130		3.22	6.4
	0-100				0.37	8.30	
Road	0-30	795	1.10	n.d.		n.d.	0.6
	30-100	417	1.35	n.d.		n.d.	0.7
	0-100				0.32	8.40	
Railway	0-30	509	1.24	**2846**		**0.33**	**21.5**
	30-100	616	1.57	1089		**2.24**	7.0
	0-100				**0.23**	**5.10**	
Military Barracks	0-30	492	1.56	140		0.51	5.2
	30-100	533	1.65	21		2.94	3.5
	0-100				0.34	5.90	

3,662,2XX,XXX,XXX
June 15, 2010

www.know-the-number.com

Center Carbon Sequestration

Carbon Sequestration

Denver, Los Angeles and New York City

☞ High Greenhouse Gas Emissions per Capita (21.5, 13.0, and 10.5 Mg eCO_2, respectively; Kennedy et al., 2009)

10% Land Carbon Storage Conterminous USA in **Human Settlements** (Churkina et al., 2010)

(i) 64% in Soils
(ii) 20% in Vegetation
(iii) 11% in Landfills
(iv) 5% in Buildings

- Protect or Increase the Carbon Storage of Cities **Terrestrial Carbon Sequestration** (Biological Sequestration - Biosequestration; IPCC, 2007)

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Carbon Sequestration in Urban Soils

(i) **Total pool of organic C** in urban soil in a specified urban area **increases** in a specified time interval through **absorption of atmospheric CO_2**, and,

(ii) In particular, the **pool of organic compounds** with **long C residence times** in urban soil **increases** over time.

Residence Times of Organic Matter, Organic Compounds and Biomarkers

(Lorenz and Lal, 2010)

Organic matter/chemical compound	Residence time
I Plant residues	
Leaf litter	Months to years
Root litter	Years
Bark	Decades to centuries
Wood	Decades to centuries
Soil organic matter (SOM)	Years to centuries
Available SOM	Years to decades
Stable SOM	**Millenia**
Black C (BC)	**Decades to millenia**
II Organic compounds	
Cellulose	Years to decades
Lignin	Years to decades
Lipids	Decades
Proteins	Decades
III Biomarker	
Lignin-derived phenols	Years to decades
Aliphatic structures	Years to centuries
Carbohydrates	Hours to decades
Proteins	Decades
Phospholipid fatty acids	Decades to centuries
Amino sugars	Years to decades

Sub-soil Carbon Sequestration

With Increase in Soil Depth

Increase

- **(i) Mean residence time of carbon,**
- **(ii) Proportions of chemically recalcitrant compounds, mineral-associated soil organic carbon, and microbial-derived soil organic carbon**

☞ **Transfer carbon into the sub-soil**

Carbon Storage Urban Forests

Conterminous US

Trees 25.1 Mg C ha^{-1} (based on data from ten cities; Nowak and Crane, 2002)

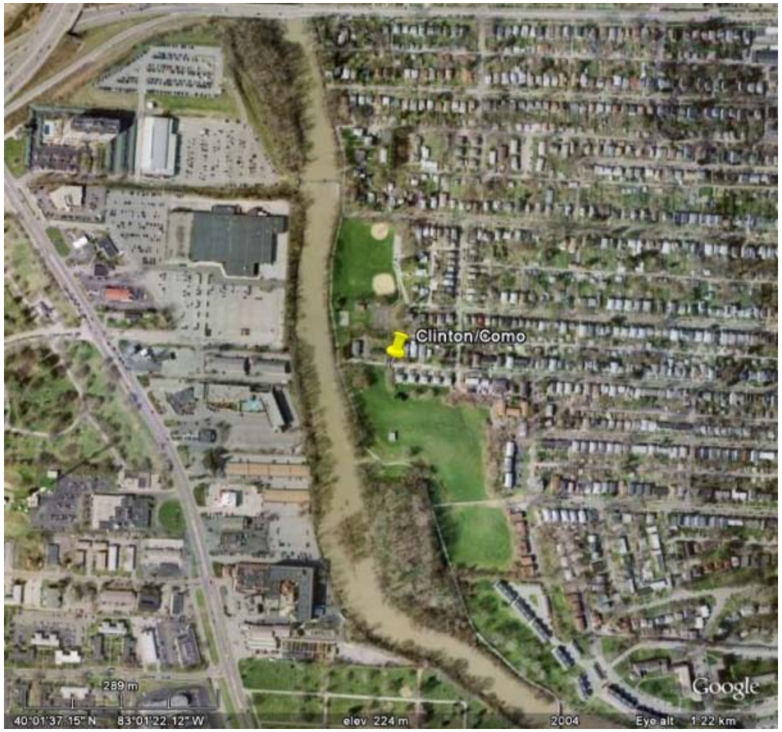
Soil 71-87 Mg C ha^{-1} to 1-m depth (six cities; Pouyat et al., 2006)

Ohio

Trees 35.4 Mg C ha^{-1} and sequester 1.1 Mg ha^{-1} yr^{-1} (Nowak and Crane, 2002)

- No data on **urban forest soil carbon**

Clinton/Como Park



- 7.9 hectare – 1.6 hectare mixed deciduous forest
- East bank of the Olentangy river
- Soils formed in moderately coarse to moderately fine textured recent alluvium – Ross silt loam, occasionally flooded (SCS, 1991)

- **Deeply rooted**, glass fragments, **charcoal**, **sediment** on surface, abundant **earthworms** Southwestern part disturbed and compacted by dam construction

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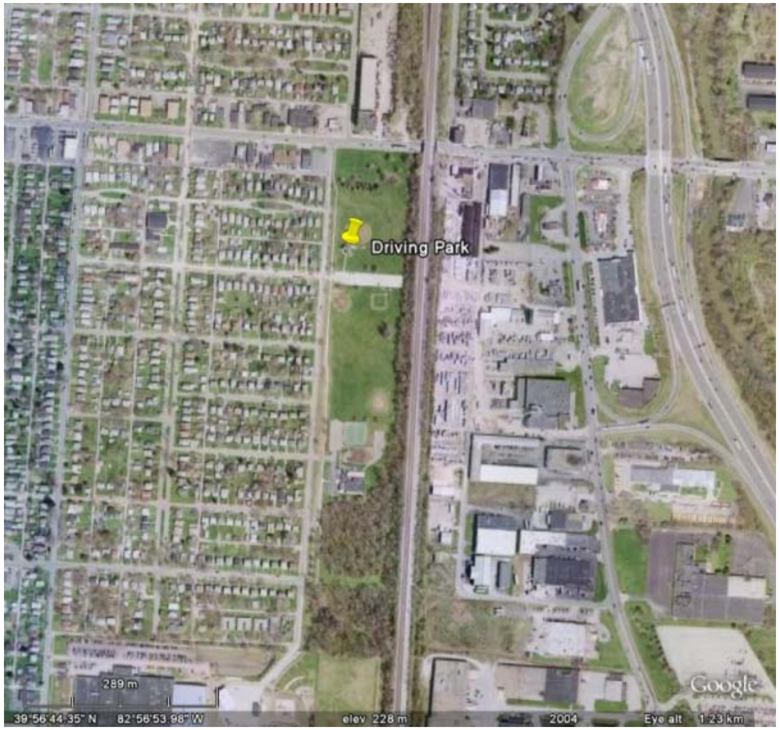
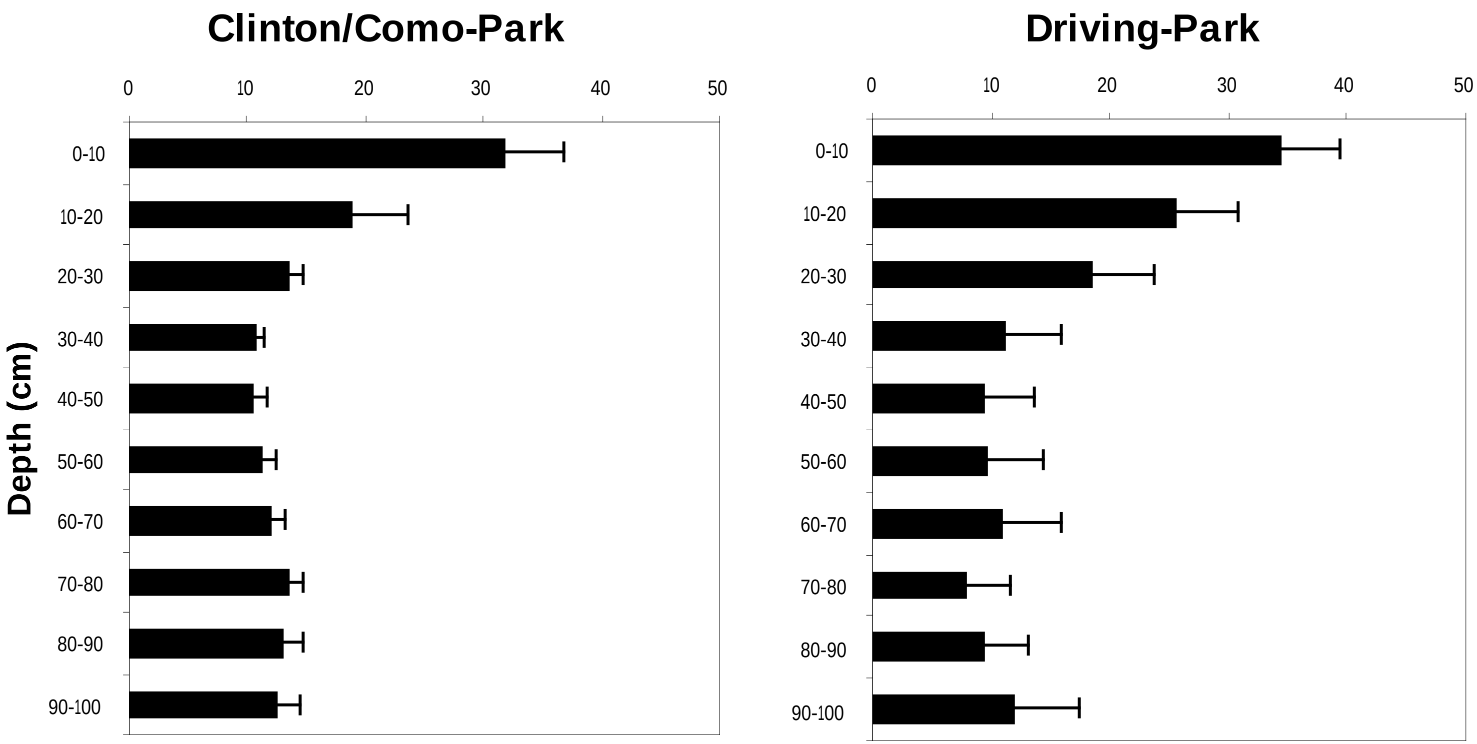
Driving Park



- 9.8 hectare – 3.1 hectare deciduous forest
- Southeast Columbus
- Racetrack for horses and automobiles 19th and early 20th century – abandoned in the 1930s
- Soils formed in medium textured and moderately fine textured glacial till – Sleeth-Urban land complex, 0 to 2 percent slopes in the northern part – Crosby-Urban land complex, 2 to 6 percent slopes in the southern part (SCS, 1991)
- Urban **waste** on surface, construction waste in sub-soil, glass fragments, **coal fragments** Eastern part disturbed by **railway** dam

Sampling

Soil Organic Carbon Stock (Mg ha^{-1})



0-100 cm: **146.7 Mg ha^{-1}** **148.3 Mg ha^{-1}**

49-239 Mg ha^{-1} Ohio Forests (1,151 Mg ha^{-1} Histosols) (Tan et al., 2004)
97.0-145.3 Mg ha^{-1} New York City (Shaw et al., 2009)
115.6 Mg ha^{-1} Baltimore (Pouyat et al., 2009)

Center Carbon Sequestration

Conclusions

Carbon storage in urban forest soils must be included in the carbon budget for Ohio (8.5% of land area currently under urban land-use)

Urban forests must be protected - effects of urban forests on the climate not entirely known, i.e.,

(i) Cooling through reduction of atmospheric CO_2 directly by C sequestration and indirectly by replacing fossil fuels with woody biomass (Richter et al., 2009)

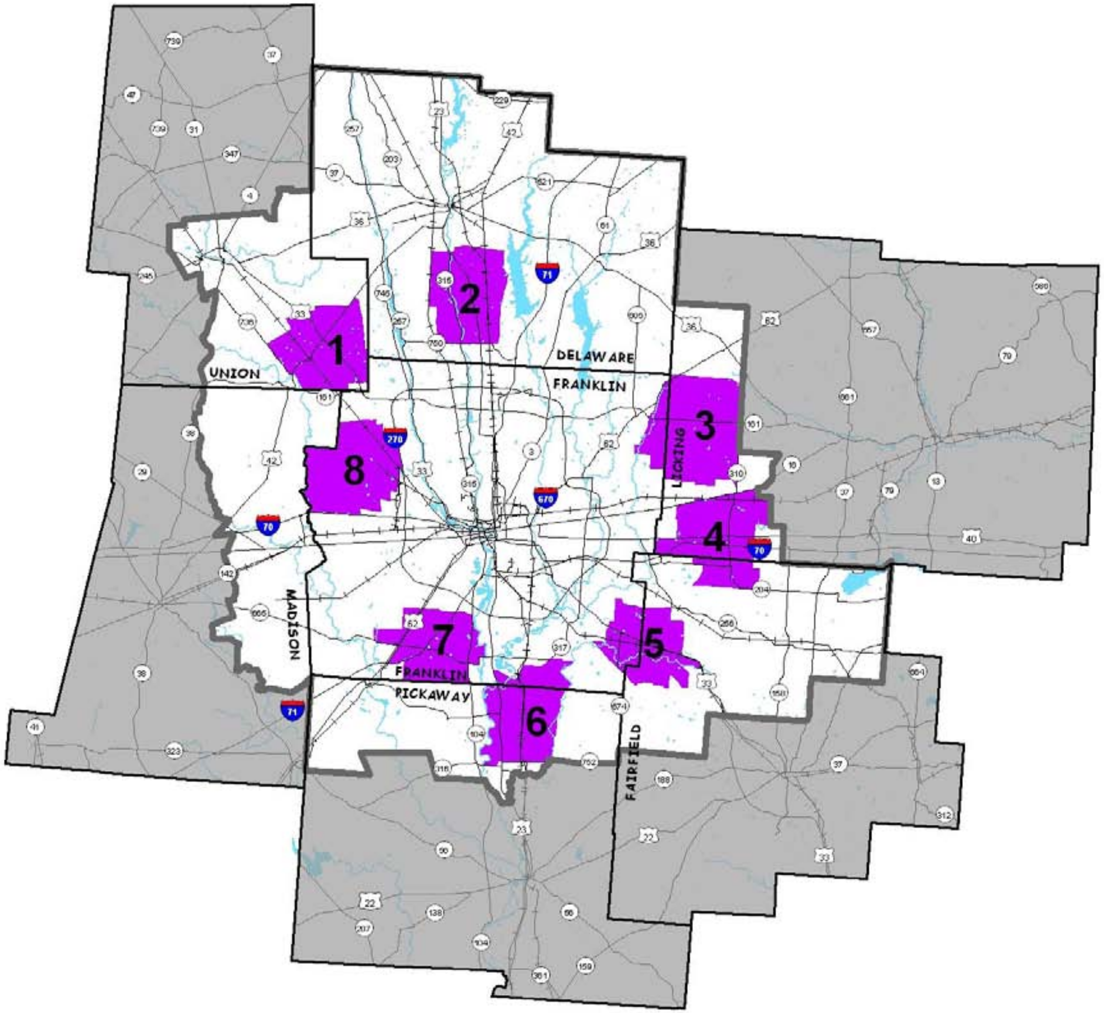
(ii) Cooling or heating through emissions of biogenic volatile organic compounds (BVOCs) and their effects on aerosol, ozone and cloud formation (Goldstein et al., 2009; Kiendler-Scharr et al., 2009)

(iii) Biophysical effects (albedo, hydrology)

Carbon Sequestration Franklin County Land Use Cover Database (2001)

Land use or cover	Hectares	%
Open Water	3,867	1.6
Low-Intensity Residential	**39,315**	**16.4**
High-Intensity Residential	**53,225**	**22.2**
Commercial/Industrial/Transportation	**31,892**	**13.3**
Developed, high-intensity	14,657	6.1
Bare Rock/Sand/Clay	1,546	0.6
Deciduous Forest	**24,752**	**10.3**
Evergreen Forest	236	0.1
Mixed Forest	36	0.0
Shrub/scrub	167	0.1
Grasslands/Herbaceous	1,891	0.8
Pasture/Hay	15,417	6.4
Row Crops	**52,674**	**21.9**
Woody Wetlands	523	0.2
Emergent Herbaceous Wetlands	67	0.0

Developing Areas Franklin County



1. US33 Northwest
2. US23 North
3. SR161
4. East I70 East
5. US33 Southeast
6. Rickenbacker
7. Grove City
8. Hayden Run

http://www.morpc.org/trans/MORPC2030LandUseForecasts.pdf

Protection of Sequestered Carbon from Disturbance?

German Soil Protection Act 1998

§1 ...soil functions are protected sustainably or should be restored...
...impairments of natural soil functions should be kept to a minimum...

Should the natural soil function carbon sequestration also be protected to minimize the carbon loss to the atmosphere?

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