# C and N urban soil budget and its spatial differentiation in comparison with natural areas in the Wroclaw region of Poland

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**Abstract.** An assessment of C and N balance in urban soil compared to the natural environment was carried out to evaluate the influence of biological processes along with human-induced forcing. Soil C and N stocks were quantified on the samples (n=18) collected at 5 - 10 cm depth from dominated green areas and arable lands in the city of Wroclaw (Poland) and the relatively natural grassland located ca. 36 km south-west. Higher soil carbon and nitrogen levels (C/N ratio = 11.8) and greater microbial biomass C and N values (MBC = 95.3, MBN = 14.4 mg N $kg^{-1}$) were measured in natural grassland compared with the citywide lawn sites (C/N ratio = 15.17, MBC = 84.3 mg C kg-1, MBN = 11.9 mg N $kg^{-1}$), respectively. In contrast to the natural areas, the higher C and N concentration was measured in urban grass dominated soils (C = 2.7 % and N = 0.18 % of dry mass), which can be explained mainly due to the high soil bulk density and water holding capacity (13.8 % clay content). The limited availability of soil C and N content was seen under the arable soil (C = 1.23 %, N = 0.13 %) than in the studied grasslands. In fact, the significantly increased C/N ratios in urban grasslands are largely associated with land conversion and demonstrate that urban soils have the potential to be an important reservoir of C.

## 1 Introduction

Soils, depending on their managed practices, play a significant role in the terrestrial carbon (C), nitrogen (N) cycle and amount of greenhouse gases (GHGs) produced or consumed. Studies on the C and N stocks have been conducted at a wide range of ecosystems including human-modified areas [1, 2]. However, there is still a large information imbalance between the characteristics of natural and anthropogenic soils. The locally or regionally specific output fluxes of C and N through respiration in the soils for land use and land-use change are reflected by regional circumstances: natural variation within region, default soil types and covered vegetation (seasonal changes and vegetation period), specific

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land-use categories and the significance of the selected sources (e.g. non-agricultural vegetation or croplands, etc.). Soil properties (temperature, moisture, texture, available N) also contribute to release of C from the soil in the form of $CO_2$ [3]. The effect of intensive land cover changes and extensive biomes disturbance have adverse impacts on $CH_4$ oxidation (the methanotrophic activity is suppressed) [4]. The emissions of $N_2O$ from agricultural and non-agricultural soils have the largest temporal variability, as well as periodic and episodic spatial variability. The emission changes are caused by microbial transformations of N compounds (nitrification and denitrification), plants biological $N_2$-fixation, deposition of reactive N and via leaching and surface run-off, as well as by the effect of commonly used N-containing fertilizers [5]. The soil C:N ratio is to be important in driving soil respiration within a given site and across a broad range of sites. The determination of a long-term course of soil microbial biomass in which C and N plays, as well as the monitoring of the soil C and N cycle, and in the estimation of $CO_2$, $CH_4$, $N_2O$ evolution for each land use type separately. Traditionally, the grassland is characterized by greater ecosystem productivity, more soil C content and microbial biomass C and N compared with the arable lands [6]. Data on soil carbon based on soil biological and chemical variables are necessary to track the potential release of carbon and carbon sinks through differing soil-management performances. This is particularly important in urban areas, where intensive anthropogenic production systems can result in a large release of carbon compared with the natural environment. While the sources of GHG emissions must be reduced, the potential of C sequestration of urban soils and biota should be increased through the implementation of the recommended management practices on cropland soils and the restoration of poor grassland soil and vegetation characteristics.

The aim of the study was to evaluate the effects of land use practices on variation in C and N soil storage in urban sites compared to natural systems in order to determine factors controlling C and N turnover processes and their origins in the city-wide land use scale. Based on the relatively higher C and N contents in urban vs. natural soils and the lower microbial activity it is expected to assess the possibilities for pollution mitigation, such as C sequestration and nitrate leaching in long-term management systems under urbanization pressures on the environment.

## 2 Materials and Methods

### 2.1 Study Area and site characteristics

The research was conducted in the urban area of Wroclaw– the fourth largest city in Poland. The main part of the city is located to the south west of the Odra River which divides the city into 12 small islands. The total city area is 293 $km^2$, with a mean elevation of 141.4 m and a mean slope of 1.7% [7]. Complex hydrogeological conditions and intense human impact in the city (high rate of urbanization with industrialization, heavy traffic situation, individual coal-fuelled heating systems, and intensive agricultural production) are the biggest environmental threats in the Wroclaw urban area [8, 9]. Wroclaw has a humid continental climate of the moderate zone. The average annual air temperature in Wroclaw is 9.0 °C, the coldest month (January) -0.4 °C, and the warmest (July) 18.8 °C. The annual amount of precipitation is 583 mm, with the average number of wet days ranging from about 167 days per year [10].

Fig. 1 represents the main soil types and location of the study sites in the Wroclaw urban area. Wroclaw agglomeration lies on relatively good productive soils, including fluvisols and cambisols [11]. The central part of the city of Wroclaw is covered by organic materials as a result of alluvial formations deposited by moving water bodies in the bottom part of the valley of the Odra River [11]. These soils are classified as Fluvisols and Gleysols. The soils of the northern and southern parts of Wroclaw are highly variable in terms of post-glacial topography dominated by Gleyic/Stagnic Phaeozems on the southern outskirts of the city [11]. In the western part of Wroclaw, the main soils are brown soils and podzolic soils. In the north-eastern part of the city (the area of 'Psie Pole' and 'Zakrzów'), the podzolic soils dominate. Deeply transformed 'man-made' soils dominate in the main part of that territory of the city as a result of the mixing of construction compounds or completely covered by buildings and communication infrastructure [11].

In Wroclaw, agricultural lands still cover 43%, sealed surfaces 39%, forests 7%, water bodies 3.2% of the total area [7]. There is growing pressure on most valuable soils located in the southern part of the city. In the last decade, a large reduction of high-quality soils has been observed. In Wroclaw, the urbanization pressure is especially intensive in the south-eastern part of the city and suburbs, where most productive soils are located. The dominant top soil textures (88.6% of the total Wroclaw functional area including neighboring to city areas) are loams, silts or sandy clays. 60.5% of the area is used as arable land and only 4.6% as pastures. Large-size farms are focused mainly on cereal production. Approximately 16% of the whole area is currently conserved [12].

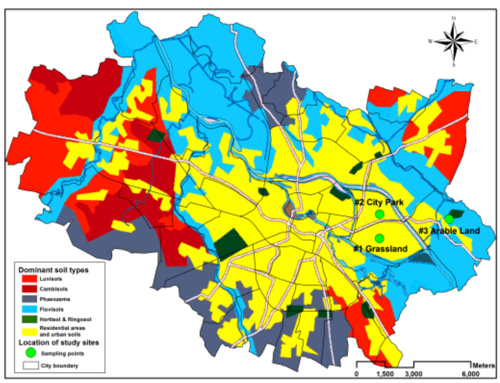


**Fig. 1.** Map of the Wroclaw study area: the mapped surface of main soil types (data source for base map layout: [11]) and the location of experiment districts.

The research was conducted at selected sites in the city of Wroclaw, which were chosen to represent the different degree of anthropogenic influence on ecosystems in a city. The experimental plot in Wroclaw is particularly well-suited for this project because it contains a complex mixture of anthropogenic and biogenic sources. The moderately polluted areas (common to the city background) with potential natural sources are co-located with areas strongly influenced by GHG emissions from different anthropogenic sources (e.g. traffic, electricity and heat production, residential heating). The first observation site, referred to as city #1 grassland is near mixed forest areas and is a moderately polluted area – city background. The area is located on A. Kosiby Street, several hundred meters southeast of the expansive public park within the area of the Meteorological Observatory of Wroclaw (University of Wroclaw) (center point coordinates are 51.1055 N, 17.0887 E, WGS-84) (fig. 1). The second sampling point has been chosen in city #2 Public Park – 'Park Szczytnicki', is situated in the northeast part of the city (center point coordinates are 51.1172 N, 17.0891 E, WGS-84). An urban agricultural field (#3 arable land) located on Bartnicza Street is the third experimental site in the city of Wroclaw. This arable field is a relatively open area surrounded by ground cover vegetation (center point coordinates are 51.1172 N, 17.1442 E, WGS-84) (fig. 1). The distance between selected locations is approximately 5 km. In the present study, the main soil characteristics of the background component (the relatively natural grasslands system) were obtained in a southwest Wroclaw neighbourhood – Sobótka region, located about 36 km southwest, taking into account the dominating regional biological and geological systems. The analysis of soil parameters at these urban sites was also combined with meteorological observations and the analysis of local conditions, historical patterns of pollution rates and impacts of land-use changes.

### 2.2 Soil Sampling and Processing

In this study, soil samples were collected at relevant depths (5–10 cm) at 6 surface locations within 0.5 m of each other. Soil parameters were analysed in a laboratory to determine the initial physical characteristics (soil texture; soil bulk density; soil water content/moisture; water holding capacity) and chemical properties (total nitrogen and carbon (C, N) contents; soil acidity (pH); soil microbial biomass carbon (MBC), carbon isotope signature ($\delta^{13}C$). All the analyses were conducted at the Department of Soil Science of Temperate Ecosystems, Georg August University of Goettingen, Germany. Samples were examined primarily to determine their physical and chemical properties. The soil texture data in the study sites was provided by the soil profile description at 10 cm soil depth for 6 soil samples (each study site) based on the pipette method. Measures of the soil water content, maximum water-holding capacity (WHC) and dry mass were calculated by gravimetric method. Water contents of 40-60% of WHC equal to suction pressures of 0.01-0.03 MPa [13]. The bulk density is often used as a measure of soil structure. The core method was applied for the determination of soil bulk density [13]. The solubility of various compounds in soils is influenced by soil pH (e.g., heavy metals) as well as by microbial activity. A pH measurement is normally made using an electrometric method [13]. Soil pH was determined with a glass electrode in 1:2 soil: water solution (w/v). The metal content was measured in the surface soil samples. The ICP-MS analytical technique was used to measure the concentration of common elements (Al, Cd, Cr, Cu, Mn, Ni, Pb, Zn, B, Ba, Fe, etc.) in soils. Analysis of total C and N, and the C/N ratio provides data on the carbon and nitrogen supply to soil microflora and plants [13]. The air-dried soil (namely the dry combustion method [13]) was used for C andN content, and isotopic composition analysis. The fractions of humus compounds were extracted from soil using NaOH-extractable materials [15]. The NaOH extract was separated into humic and fulvic acids and washed successively with $H_2SO_4$. Soil microbial biomass carbon (MBC) and nitrogen (MBN) were determined using the chloroform fumigation-extraction (CFE) method [16]. The organic C and total N content of the filtered extracts of fumigated and non-fumigated soils were measured with a multi N/C analyzer (multi N/C analyzer 2100, Analytik Jena, Germany). The carbon stable isotope ($\delta^{13}C$) measurements of the dry soil and the freeze-dried leachates of the fumigated or non-fumigated $K_2SO_4$ extract from the same soil samples were conducted using an isotope ratio mass spectrometer (Dino – Delta Plus XP IRMS).

## 3 Results

Soil texture (sand, silt and clay content) is an important factor that relates to the soil performance functions, influencing the water holding capacity and ability to store nutrients. If a soil is sandy, the water moves through the soil quite well; this soil has good conductivity while disadvantageous to water storage. The clayey soil, is less susceptible to leaching water but have good water storage for plant growth [17]. The highest values of sand content and low silt value were obtained in urban soils compared to the relatively natural grasslands system in the Sobótka region (Wroclaw suburb). Soils in the Sobótka region have a texture of 10.6% sand, 75.3% silt, and 14.1% clay within the first 10 cm (Table 1).

**Table 1.** Particle-size distribution of soil layer in the study sites.

| Study site | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|
| Grassland | 74.39±6.59 | 11.75±3.83 | 13.86±2.82 |
| Arable Land | 70.53±0.98 | 17.45±0.69 | 12.02±0.72 |
| Grassland Sobótka | 10.62±0.64 | 75.28±0.64 | 14.09±0.13 |

Clay soil under the grassland was found to have the lowest levels of N leaching, and the highest in soil dominated by sandy-texture used as arable land. All the results showed the differences in soil properties as a result of soil management and the differences in the soil organic matter. Soil properties such as clay, pH, organic carbon, nitrogen availability influence the size of the microbial biomass. The total organic C, microbial biomass C and N respond quickly to management changes [13]. The main soil parameters analysed for measurement plots in the city of Wroclaw (soil bulk density, pH, carbon, nitrogen content, microbial biomass) and $\delta^{13}C$ in the soil are summarized in tables 2 and 3.

**Table 2.** The main soil characteristics (0-10 cm) at the urban vs natural sites.

| Parameters (units) | Grassland | Arable Land | Grassland Sobótka | Methodology |
|---|---|---|---|---|
| Soil bulk density (g/cm$^3$) | 1.23 | 1.15 | 1.18 | core method |
| pH in $H_2O$ | 5.29 | 5.59 | 6.49 | electrode method |
| Water holding capacity (WHC), % | 35.69 | 28.73 | 37.46 | gravimetric |
| Humus (%) | 4.31 | 2.11 | 5.03 | NaOH-extractable method |
| Total C (% of dry mass) | 2.73 | 1.23 | 2.91 | dry combustion method |
| Total N (% of dry mass) | 0.18 | 0.13 | 0.25 | |
| Soil C:N ratio | 15.17 | 9.94 | 11.81 | |
| Microbial biomass C (mg C kg$^{-1}$) | 84.31 | 77.11 | 95.27 | chloroform fumigation-extraction (CFE) |
| Microbial biomass N, (mg N kg$^{-1}$) | 11.93 | 15.61 | 14.44 | |

The soil bulk density, sampled by determining two 5-cm deep cores from each plot, ranged between 1.15 g/cm$^3$ to 1.23 g/cm$^3$ (table 2). The selected urban grassland is characterized by more porous soil compared to other locations. In clay soils, the bulk density varies with soil water content (through swelling–shrinkage properties). The soils in the urban and natural grasslands have some of the highest water holding capacity (WHC) levels ranging from 35 – 38 % in comparison with arable lands. The pH values of the soil varied between 5.29 to 6.49. The highly acidic soil is represented at site 1 (urban grassland) when a less acidic soil in the outside-urban Sobótka plot. The native grassland soil in the Sobótka plot was found to have a statistically significant difference in developed humus horizons ($p<0.03$, $n=6$) close to 5 % when the agriculture lands had weakly humus content (near 2.1 %). Variation was seen in the total carbon and nitrogen content between the urban plots (from mean 1.2 % C of dry mass in arable land to 2.7 % C of dry mass in grassland) as compared to the control plot in natural grassland in the Sobótka region (value of 2.9 % C of dry mass). The highest C:N ratio of 15.17 was recorded for site 1 (urban grassland), and the lowest of 9.94 for site 2 (arable land) which could be the most-favorable result of many years of intensive agricultural cultivation in this area (Agricultural Experimental Plant 'Swojec' in Swojczyce region). Soil in this site is definitely poorer in carbon and nitrogen compared to other study sites. The richest in terms of nitrogen content, the soil (relatively natural) is located in the outside-urban location – the Sobótka study area. Microbial biomass is a measure of changes in the total soil organic C and N and can be a better indicator of changes induced by tillage [13]. The microbial biomass C measured in the Sobótka area had the highest range (95.27 ± 6.09 mg C kg$^{-1}$), while the least amount of biomass C was measured in arable land (77.11 ± 4.31 mg C $kg^{-1}$). However, the soil`s N content in this plot was accompanied by increases in the microbial biomass N, (15.61 ± 0.81 mg N $kg^{-1}$) mainly due to the input of N-fertilizer nutrients into soils.

Measurements of natural $\delta^{13}C$ abundance in soil particles can be used to characterize the origin and changes in the rate of C dynamics. Many factors related to compound-specific decomposition in soil organic matter contributing to variations in isotopic composition of soil carbon ($\delta^{13}C$). The isotopic signature of carbon in soil matter (table 3), at all sites had not differed significantly ($p>0.05$, n=12). However, at the arable land site, a clear enrichment of $\delta^{13}C$ towards more positive values of -26.56 ± 0.7‰ than at the other locations(grasslands) was observed. It may reflect the role of living vegetation: the difference in isotopic signal from grasses and crops. Overall, it is clear that the soil transformation effect had a strong influence on shifting the $\delta^{13}C$ in one direction. It again confirms the fact that the arable soils are strongly converted in comparison with other study sites and shows distinctive pattern changes in soil C sequestration: the C content and C sequestration are slow in arable soils as compared to grasslands.

**Table 3.** The isotopic composition of carbon ($\delta^{13}C$) in soil matter at the urban vs natural sites.

| **Soil $\delta^{13}C$ (0-10 cm)** | | | | **Methodology** |
|---|---|---|---|---|
| **Parameters (units)** | **Grassland** | **Arable Land** | **Grassland Sobótka** | |
| $\delta^{13}C$ dry soil (‰) | -27.76±0.41 | -26.56±0.67 | -28.14±0.25 | IRMS |
| $\delta^{13}C$ fumigated (‰) | -26.64±0.27 | -25.91±0.17 | -26.29±0.15 | chloroform fumigation-extraction (CFE) + IRMS |
| $\delta^{13}C$ non-fumigated | -27.47±0.38 | -27.28±0.15 | -27.37±0.17 | |

Organic matter plays a number of functions in the soil. Furthermore, in microbial/ plant metabolism not only is the carbon and nitrogen cycle involved, but also the number of macroelements and microelements. They also affect the physical, chemical, and biological properties of soils [13]. The mobility and migration of elements (mainly heavy metals) is mainly controlled by soil texture, pH, and organic matter content as well as anthropogenic factors (use of fertilizers, manures and pesticides, industrial, transportation pollution, etc.). Most heavy metals are the origin of soil-forming processes, but contamination with them is typically caused by industrial activity, agricultural chemicals, waste handling or other activity [13]. The characterization of the trace metals content in the soils of the city of Wroclaw is shown in Fig. 2.

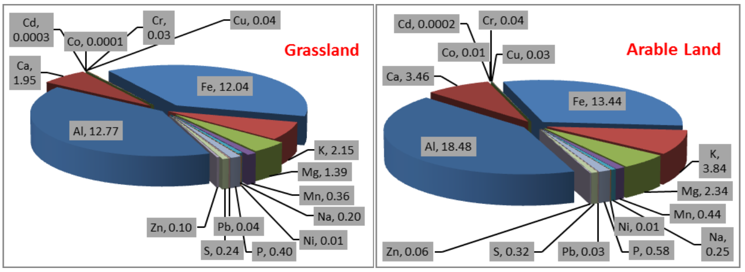


**Fig. 2.** Total content of trace metals [$mg \cdot g^{-1}$] in soils across the measurement points in the Wroclaw urban area.

There is a significant difference between individual elements in terms of harmful effects for soil pollution. The analysis of metal content according to the IUNG guidelines (Institute for Soil Science and Plant Cultivation, Poland) [18] had not indicated soil contamination with heavy metals in the studied areas. In the case of the concentrations of lead, zinc, nickel, and cadmium, the increased levels were found in comparison to the geochemical background. However, in none of such cases, the IUNG metals exceeded permissible levels (for Pb – 0.05 mg·g$^{-1}$, Zn – 0.09 mg·g$^{-1}$, Ni – 0.25 mg·g$^{-1}$, Cd – 0.0005 mg·g$^{-1}$) [18] were not exceeded. The detectable concentrations of zinc, and only in grassland soil samples, were the concentrations above the threshold value (0.10 mg·g$^{-1}$). The results also show that agricultural land has a higher percentage of samples with a higher concentration of macroelements than other land uses in the city.

## 4 Discussion

The analysis of the chemical parameters of soil samples obtained from urban grassland showed a significant increase in the ratio of C: N content in soil as compared to a natural ecosystem, which may be related to the effect of land transformation [19] and illustrates a large ecosystem`s ability to store carbon. Microbial biomass is also an early indicator of changes in total soil organic carbon [13]. The microbial biomass varies depending on land use practices and different inputs of organic matter into soils. The results showed the microbial biomass is generally lowest under agricultural land, and increased from urban grassland to natural grasslands system. Higher soil carbon, nitrogen levels (C/N ratio = 11.8) and greater microbial biomass of C and N values (MBC = 95.3 mg C kg$^{-1}$, MBN = 14.4 mg N kg$^{-1}$) were determined in the grassland compared with the citywide lawn sites (C/N ratio = 15.17, MBC = 84.3, MBN = 11.9 mg N kg-1). Certain sites (urban and natural grasslands) had similar soil moisture and a quite similar C:N rates. Generally, the soils with more clay have a higher microbial biomass [20] indicating more water storage and including a greater organic C and N rate. The obtained results showed significant differences among measurement locations for water holding capacity in converted arable soils in comparison with meadow-like lawns. This is a result from soil structure and management practices. It was found that the spatial variability in the soil C:N ratio was also represented by differences in humus content among our measurement locations (lower in arable soil and higher under grassland).

The soil properties that affect microbial biomass are soil pH and the number of macro- and microelements. Again, the range of microbial biomass C and N for the urban measured sites was small when compared to a broader range of natural sites. The elevated concentration of metals in the soil exceeded permissible levels and may have an impact on the soil respiration processes as well as microbial content and activity of microorganisms [21]. The effect of metal concentrations on soil respiration was not measured in this study. The determination of the impact of metal contamination on soil microbial biomass, however, requires additional analysis of enzymatic activity.

Soil contains substantial amounts of carbon, which can contribute to GHG emissions through various respiration pathways. The isotopic signature of soil carbon dynamics is a useful tool for distinguishing the amount and turnover of soil C derived from ecosystems as well as from natural abundance or anthropogenic origins [22]. The isotopic analysis showed that the carbon stable isotopes ($\delta^{13}C$) of native and urban soils were not very different. The enriched values of soil $\delta^{13}C$ under arable land as compared with grasslands represent the effects of land use changes, namely vegetation change – grasses into crops.

## 5 Summary

The soil's chemical and physical properties across urban and natural land use and soil cover types were analysed in this study. The region-specific land management effects were estimated for the identification of the controlling factors in optimally managing the soil C pool on an urban scale. The variation of the carbon and nitrogen soil budget is associated with the measured sites within each soil texture, physical and chemical soil properties. The arable land showed significant changes in soil C and N storage, indicating that management practices influence the C and N turnover processes within the soil profile. The positive relationship of the soil C:N range at the studied sites with the soil properties demonstrates that some of the locations (citywide lawn sites) could be strong C sinks in an urban area.

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