SOIL CHEMISTRY UNDERPINS THE LEGACY OF CHARCOAL HEARTHS: EXPLORING POTENTIAL BASIS FOR EDUCATIONAL MATERIALS

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Abstract
Charcoal production hearths are significant cultural landscape features and convey profound anthropogenic effects on soil properties. Whereas pyrolysis causes irreversible changes in the wood chemical structure, charcoal production residues alter underlying soil environment (stratigraphy and chemical composition). The most substantial changes consist in increased stable forms of organic carbon concentrations, which gain unique nutrient properties (nitrogen content augmentation to the detriment of metals bound in ashes and mineral soil) over centuries.
This contribution compares the elemental composition (C, N, P, K, Ca, Mg, S and Fe) of relict hearth layers and their total stocks to neighbouring forest soil. The hearth soil layers were predominately C and N enriched while depleted of Ca, Mg, P and Fe. Total hearth carbon stock exceeded that of forest soil more than twice. Total sulphur content, however lower in upper soil layers, was also higher in the hearths. Hearths can be perceived as meaningful hotspots of long-term carbon storage. The heritage of charcoal production in forestry should be well communicated to public because of (1) high number and density of hearths in Central European landscape, as well as (2) their ecosystem stability protection and stable carbon sequestration potentials.

Key words: carbon sink, environmental education, soil, nutrient stock, elemental analysis

Introduction
Charcoal production hearths are important geomorphic features of Central European cultural landscape. Charcoal production was conducted for centuries and has considerably affected forest stands in terms of their fragmentation, composition and edatope (Hirsch et al. 2017; Raab et al. 2019).
Due to their high density and differentiation from surrounding soil, ecological and environmental importance of the hearths might be more accented within scientific as well as laic public in such forms as are shown at URL [1; 2; 3]. Beside tourist and historical charisma of hearths, we would like to show their ecological importance, which could be assigned in the tourist trails as well.
Remains of charcoal mounds not only possess pedoarchaeological significance but also represent hotspots of different soil properties (Borchard et al. 2014) due to high temperatures and enrichments (ash, tar, biochar etc.) during pyrolysis (Knicker 2011). As a result of charring and site preparation (landscaping by creating a production platform) in the topsoil, there was blending of soil masses, changes in soil stratigraphy and concentration of individual elements (Hirsch et al. 2017).
Soil chemical composition shifts caused by charcoal production have been addressed in several studies: focusing on volumetric characteristics (Mikan, Abrams 1995), content of C, P, K and other elements (Young et al. 1996).
The outcomes of the treatises sometimes differ on the site significance of hearths. Some of them mention the defavorization effect on the soil environment, or rather on vegetation. Charcoal hearths have a differentiated impact on the concentration of various elements (Mikan, Abrams 1995; Young et al. 1996). Beside site evaluation of hearths, a few studies focus on the overall nutrient stock.
The aim of his study was to compare chemical properties of charcoal hearths with surrounding forest soil. As we believe, the results could be used as a handout for a trail information board to underline hearths importance not only due to historical legacy but also due to environmental significance. The legacy effects and cultural heritage of traditional land use practices in forestry fully deserve general public awareness emphasizing balanced carbon budget and natural renewable resources.
Focusing on element contents (C, N, P, K, Ca, Mg, S and Fe) to the soil depth of 40 cm, we assumed that the content of organic carbon increases in hearth soils and in this connection also the organic matter of bound nitrogen and phosphorus.

Material and Methods
Forest stands situated 10-30 km east and north of Brno (Czech Republic) between the north latitude coordinates of 49°13´N; 16°40´E and 49°26´N; 16°50´E were chosen as the area of interest. The altitude of the area is from 390 to 590 m a.s.l. The area is characterized by topographical

fragmentation. The study area was divided into three 5 × 5 km squares (northern, central and southern). Within the study area we detected and verified 116 hearths from which we selected 6 for sampling and analysis (2 per each square). Hearts were last used ca. 150 years ago according to historical records.
Sedimentary rocks (graywacke, slope loam) predominated in the S and N squares and an admixture of granodiorite and paragneiss predominated in the central square. The rocks of the geological subsoil are recovered by differentially thick loess loam (30–60 cm). Eutric Cambisols (IUSS Working Group WRB 2014) predominate from the soils, altering rarely with Haplic Luvisols.
The samples were collected both from the hearths and from the soil probes excavated near the hearths at distance of 10-15 m following the contour line. The thickness of the individual horizons was detected and samples were taken as undisturbed (82 in total; 2 repetitions per horizon) for bulk density assessment and mixed (46 in total; 1 per horizon) for chemical analysis.
Bulk density (ρ_d) was determined as the weight of 1 cm^3 of the intact sample dried to the constant weight (105°C). Total carbon (TC), total nitrogen (N), and total sulphur (S) were assessed using elemental analysis for the samples sieved through a 2 mm sieve and milled to a maximum particle size of 0.25 mm. Determination was performed with the application of Vario Macro cube analyzer, Elementar, Germany, burning the dry sample at 1125°C and weighing 100 mg ±5 mg. Determination of P, Ca, Mg, K and Fe was carried out after total mineralisation of the sample sieved through a 2 mm sieve by microwave decomposition in hydrofluoric (HF) and nitric (HNO_3) acids in a wet process by means of FAAS.
The amount of the individual elements was calculated for each horizon according to ρ_d as a weight per area of 1 m^2. The amount of the element was converted to the fixed depth of 0-10; 10-20; 20-30 and 30-40 cm according to the thickness of the horizons both separately and cumulatively to determine the total stock at the depth of 0-40 cm. The results were expressed for both the individual horizons and fixed depths by the average values of the element content with standard deviations. Data were evaluated to compare element contents in the hearths and the soil using two-factor parametric ANOVA at α= 0,05.

Results

The humus (H) horizons (Table 1) indicated the lowest and similar thickness. The organomineral (A) horizons evinced similar thickness, but the substantial differences of soil stratigraphy lied on presence of Azp horizon leading to deeper position of mineral horizons in hearths. Bulk density increased with augmenting depth (min. 0.46 g cm^{-3} at the H horizons; max. more than 1.5 g cm^{-3} at the mineral horizons). Humification decreased with the increasing depth. The organomineral Ah horizons were significantly more humic in the hearths, which also demonstrated high TC content at a considerable depth down to 15-20 cm.

Tab. 1: Thickness, bulk density and total carbon concentration in genetical horizons separately for hearths and surrounding soils.

sampl. site	hor.	n	thickness [cm]		ρ_d [g cm^{-3}]		TC [%]	
			$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
hearth	**H**	6	2.8	1.7	0.46	0.12	33.1	11.4
	Ah	4	5.5	2.1	0.85	0.19	18.9	8.6
	Azp	6	11.5	5.1	0.73	0.06	21.7	8.5
	Bzp	6	11.8	10.4	1.31	0.33	1.6	1.8
	C	5	-	-	1.58	0.14	0.6	0.3
soil	**H**	2	2.5	0.6	0.64	0.02	35.4	4.3
	Ah	5	6.0	1.0	1.01	0.14	5.1	2.3
	E	2	9.5	2.1	1.55	0.08	0.7	0.6
	B	8	13.5	3.1	1.38	0.23	0.9	0.2
	BC	2	-	-	1.45	0.03	0.3	0.2

The soils were significantly richer in TC and also in N especially in the organomineral horizons (Table 2) in the hearths. There was the higher stock of N in the forest soil and it was more than doubled in the organic H horizon. The P content was comparable in the humus horizons, but significantly higher in the mineral horizons of the forest soil. The same trend was observed for K, Ca, Mg and F. The sulphur content was generally higher at mineral horizons of the hearths. When converted to the fixed depths, the C-stock in the hearths was more than twofold and the stock of N, K and S was slightly higher (Table 3; Fig. 1). At the same time, there was a sudden increase in the stock of Con the soil surface of the hearths while the mineral horizont indicated a stock comparable to the forest soil. On the contrary, there was a higher stock of P, Ca, Mg and Fe in the mineral horizons of the forest soil. The sulphur content was lower in the organic horizons of the hearths, but higher in the overall depth of 0–40 cm due to its enhanced content in the mineral horizons. Overall, the Fe content was higher in the forest soil.

Tab. 2: Element stocks in genetical horizons separately for hearths and surrounding soils.

sampl. site	Hor	TC [kg m^{-2}]		N [g m^{-2}]		P		K		Ca		Mg		S		Fe	
		□	sd	□	sd	□	sd	□	sd	□	sd	□	sd	□	sd	□	sd
hearth	H	4.3	3.2	163	121	26	17	97	69	21	12	107	77	13	9	27	17
	Ah	7.9	1.2	209	80	151	138	212	146	174	150	720	486	14	8	151	138
	Azp	17.3	7.4	368	155	242	129	646	491	247	133	1263	533	18	14	242	129
	Bzp	1.6	1.4	93	33	226	222	993	640	789	432	2682	1367	10	8	226	222
	C	1.4	0.9	117	34	462	227	1299	819	1243	504	4507	1298	34	59	462	227
soil	H	5.8	1.9	240	66	31	6	83	24	25	4	110	31	25	7	31	7
	Ah	3.0	1.4	145	56	173	32	344	183	200	86	1240	605	17	9	173	32
	E	1.0	0.0	87	28	454	168	1509	336	973	289	2661	1209	4	2	454	168
	B	1.4	0.9	110	39	447	302	1264	1136	952	568	3454	1154	10	7	447	302
	BC	0.7	0.7	75	31	186	186	1055	908	1113	224	5517	3561	5	5	186	185

Tab. 3: Element stocks in the fixed depths and in the total thickness of 0–40 cm separately for the hearths and the surrounding soils.

sampl site	Hl. [cm]	TC		N		P		K		Ca		Mg		S		Fe	
									[kg m^{-2}]								
		□	sd	□	sd	□	sd	□	sd	□	sd	□	sd	□	sd	□	sd
hearth	0-10	12.3	4.0	0.37	0.11	0.21	0.07	0.49	0.21	0.24	0.11	1.09	0.35	0.028	0.01	1.42	0.64
	10-20	9.4	6.9	0.23	0.13	0.24	0.08	0.64	0.33	0.38	0.24	1.56	0.36	0.016	0.01	2.17	1.42
	20-30	2.4	2.5	0.10	0.05	0.22	0.09	0.91	0.48	0.74	0.39	2.58	0.74	0.018	0.02	3.33	1.37
	30-40	0.8	0.5	0.07	0.01	0.36	0.17	0.11	0.64	0.79	0.21	2.86	0.82	0.020	0.03	4.10	0.68
	0-40	27.0	11.6	0.78	0.29	0.93	0.20	2.89	1.19	2.15	0.83	8.05	1.34	0.07	0.07	10.71	3.85
soil	0-10	10.7	4.2	0.40	0.08	0.21	0.07	0.54	0.30	0.29	0.15	1.63	0.77	0.038	0.01	1.84	0.90
	10-20	3.1	4.5	0.07	0.07	0.23	0.19	0.80	0.45	0.62	0.23	2.58	0.66	0.007	0.00	3.38	1.58
	20-30	0.8	0.4	0.07	0.02	0.34	0.20	1.00	0.63	0.76	0.29	2.93	0.66	0.006	0.00	4.40	1.77
	30-40	0.7	0.4	0.07	0.02	0.30	0.18	0.92	0.74	0.97	0.44	2.99	0.63	0.006	0.00	5.47	2.42
	0-40	11.6	3.1	0.61	0.14	1.17	0.55	2.23	2.23	2.58	1.12	10.14	1.94	0.06	0.02	15.21	6.61

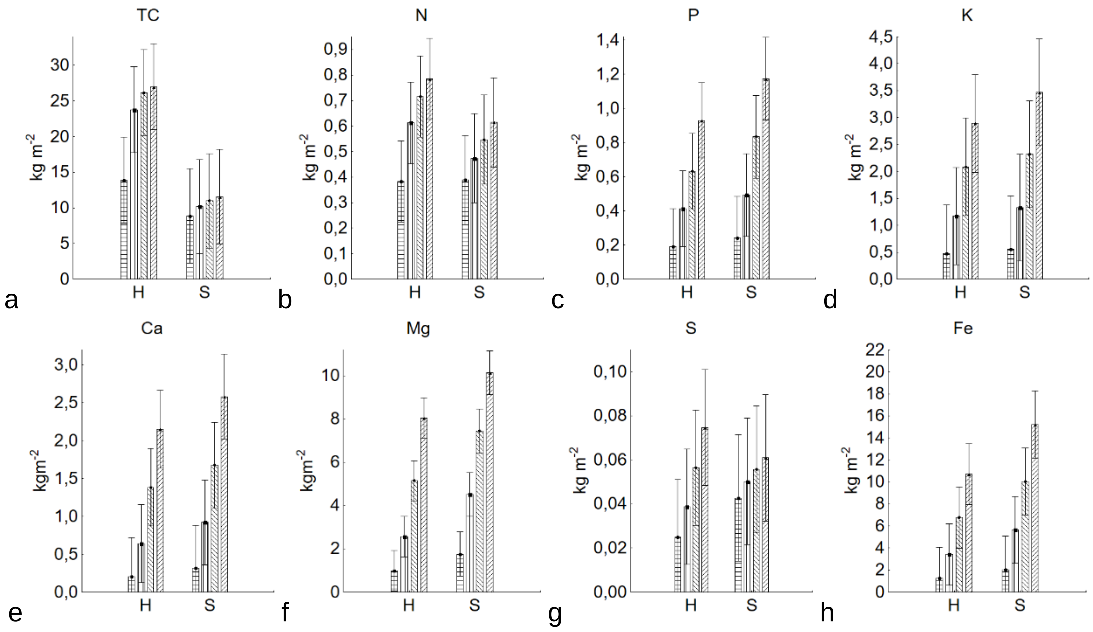

Fig. 1: The cumulative element contents in the fixed depths in the soil of the hearth and the surrounding forest. (H – hearth; S – forest soil; 0-10 cm; 10-20 cm; 20-30 cm; 30-40 cm).

Discussion

The soils of charcoal hearths were classified according to WRB as Spolic Technosol (Humic, Thaptotransportic) over Cambisol by the authors(Hirsch et al. 2017). The related terrain modifications generally result in higher thickness of horizons by modifying the site into the plateau and leaving the part of pyrolytically decomposed biomass or imperfect cleaning of the hearth site.

In our work, similarly to the study by Borchard et al. (2014), bulk density was significantly lower in the hearth, moreover in the greater depth than in the surrounding soil (Table 1). In the cited work (Hirsch et al. 2017), the authors found out the overall lower concentration of organic carbon. Charcoal hearth appears to be an important landscape element for organic carbon in terms of long-term carbon stock in the stabilized form (Knicker 2011; Schmidt & Noack 2000). Nevertheless, the cited authors also highlighted the significant influence of management following charring and hearth age (cf. Hardy et al. 2017). The key time limit for the concentration of N was estimated to be 150 years (Raab et al. 2019) when the nitrogen content, as a result of charring completely volatilized, increases by binding to the organic matter and redeveloped soil biota.

The sulphur content was not assessed as significantly different from the surrounding soil in the similar works (Raab et al. 2019). In our work, the total sulphur stock was comparable, but with a completely various depth distribution (Table 3).

Alterations in the concentrations of other elements were also reported to be diverse in other works in comparison with the surrounding soil, under the influence of such factors as age or more precisely time since the last use of the hearth, the repetitive character of its use, comparative chemistry of the surrounding soil or rather the soil type (Borchard et al. 2014; Mikan and Abrams 1995; Young et al. 1996).

From this contribution, the informations could be extracted as part of tourist trails (information boards) to more spread knowledge of importance of these environmental objects in landscape. From the point of view of transformation, cycles and the study of the sequestration potentials of biogenic elements, hearths, with their immeasurable number in the European landscape, represent a significant and largely unexplored, unique natural lab. Hearths facilitate understanding of long-term effects of the biochar application and associated trade-offs between climate mitigation and other environmental impact categories.

Conclusion

The material extraction of information boards might contain following information (in more consumable form): The hearth environment was characterized by a more distinctive topsoil stratification in favour of charcoal-rich layers with the carbon concentration of over 20 %, average thickness of pyrogenic carbon rich horizons of 11–12 cm and bulk density of 0.73 g cm^{-3} on average, making these values the lowest of organomineral and mineral horizons even in comparison with the surrounding forest soil. Of the elements, the values of C content were more than twofold higher in the hearths. Furthermore, the values of the N content were enhanced and the values of K and S contents were also slightly higher. On the contrary, the concentrations of P, Ca, Mg and Fe were lower. Hearths represent a significant reservoir of carbon in a stable pyrogenic form, as well as the environment with the increased concentrations of nitrogen and partly sulphur. Their cultural-historical dimension, continuity (long time series), diversity, relatively good mapping and mitigation potential towards global climate change make hearths important landscape features that deserve more public attention and can play a key role in awareness-raising activities not merely in the broader environmental protection context.

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Souhrn

Milíře jsou významnou součástí krajiny nejen s kulturně historickým odkazem, ale také se značným ekologickým a environmentálním významem. Stanovení prvkového složení (C, N, P, K, Ca, Mg, S a Fe) na šesti milířích brněnska poukázalo na značnou odlišnost v porovnání s okolní půdou. Milíře se vyznačovaly výraznější stratifikovaností *topsoil* ve prospěch vrstev s koncentrací uhlíku i přes 20 %. Významné rozdíly v objemové hmotnosti i obsahu dalších prvků poskytují dostatečný důvod pro zařazení tohoto tématu jako součásti naučných stezek zaměřených na témata historického využití krajinných součástí.
Milíře představují významnou zásobárnu uhlíku ve stabilní pyrogenní formě a také prostředí se zvýšenou koncentrací N a částečně S. Jejich kulturně historický rozměr, kontinuita, rozmanitost, relativně dobré vymapovaní a mitigační potenciál směrem ke globální změně klimatu z nich činí důležité krajinné prvky, které si zaslouží větší pozornost širší veřejnosti a můžou sehrát důležitou roli při osvětových činnostech i v širším kontextu ochrany životního prostředí.

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