SOME REMARKS ABOUT THE EFFECT OF SMOKE FROM CHARCOAL KILNS ON SOIL DEGRADATION

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Abstract. The charcoal kilns under study were situated in the Polish Western Carpathiens (Bieszczady). Aromatic hydrocarbon products of wood burning in the kilns were identified. The rate of decomposition of beech leaves was relatively high as environmental conditions enhanced decomposition. The intensity of soil metabolism is increasing during a long-term exposure to smoke, which is one of the indicators of anthropogenic disturbance resulting from organic factors.

Keywords: charcoal kilns, decomposition, smoke chemical composition, soil degradation

1. Introduction

In recent years there is an increasing tendency to return to the old method of producing charcoal by wood burning under restricted air supply in kilns placed directly in a forest. This method has many economic advantages, primarily it reduces the costs of wood transport, provides jobs for workers far from civilization, is cheap and convenient. At the same time a view is propagated that this method does not disturb natural environment to the extent that National Parks are proposed as the places of charcoal production.

In Poland, charcoal is produced by this method in several regions but most commonly in the Bieszczady Mountains – the Polish part of the Western Carpathians.

The objective of this paper is to answer the question whether charcoal preparation in the region adjoining the Western Carpathian National Park has a degrading effect on the soil. The rate of organic matter decomposition was considered as an index of degradation. This is a comprehensive index, reflecting a net result of the effect of many factors, and commonly used in the studies of disturbance to the ecological balance of soil systems (Grodziński and Yorks, 1981; Zwoliński *et al.*, 1988; Bieńkowski 1990a; Hattori, 1992; Othonen *et al.*, 1994).

2. Study Area

The charcoal kilns under study were located in the Polish, Eastern part of the Western Carpathians (Bieszczady) near the Bieszczady National Park. Over ten

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charcoal kilns were selected of which six were finally under study. Three were situated in a forest and three in an open area. In the second year of the study one more kiln was added, located in a forest valley bordering on the National Park. The time of exploitation in a given area was the basic difference among kilns (3, 10, 20 yr).

Forests represented the community of Carpathian beech *Denthario glandulosae Fagetum*, predominated by the European beech *Fagus silvatica* and the fir *Abies alba* (Michalik, 1993; Zarzycki, 1993). Also the sycomore maple *Acer pseudo-platanus* and the aspen *Populus tremula* were present. Soils were mostly acid brown and leached brown (Adamczyk and Zarzycki, 1963; Skiba, 1993). Open areas supported diverse pastures.

The study points were chosen in the areas most exposed to smoke. Control points were in areas without smoke. Each charcoal kiln consisted of a group of burners (4–6) about 2.5 m in diameter and 3 m tall. In one cycle, about 11 m^3 of wood were burnt over 72 hr. Basically, the kilns were working throughout the year with a short break in winter under most adverse climatic conditions.

3. Methods

To estimate the rate of organic matter decomposition, two kinds of indices were used. One, of a more general character, was the rate of decomposition of cellulose filters. On each occasion, 20 cellulose filters (⌀ 10 cm) were exposed in the soil at each of the study points. Cellulose filter papers on glass were vertically exposed in the soil 1–10 cm deep across the slope. The second index was the rate of organic matter decomposition in bags filled with beech leaves. In the soil of forest sites, 40 bags (15 × 15 cm) with air-dry beech leaves were exposed. Whole leaves were enclosed in polypropylene bags with a mesh size of 1 × 1 mm. Each bag contained 7 g of air-dry material. The bags were buried in the soil. The time of exposure in the soil was eight weeks during the growing season (May–July, July–October). After the exposure, the percentage weight loss was determined (Bieńkowski, 1990b; Pietr *et al*., 1995).

At the same time, soil samples were taken from the top layer (0–10 cm) to assess the content of organic matter, soil pH, contents of carbon, hydrogen, nitrogen and sulphur, the latter by using the element analyser CHNS+O, produced by Fisons Instruments (former Carlo Erba). At each point, 10 samples of identical weight were taken. They are mixed and the resulting collective samples analysed in triplicate.

Smoke samples were taken from one charcoal kiln. In the kiln from which smoke samples were taken, charcoal was obtained from beech wood. Part of the samples were taken above the outles in the upper part of the kiln and above the chimney outlet at the base of the kiln. Samples were taken by using a sampler

placed in the stream of smoke, connected with a suction pomp and with a rotameter to control the amount of smoke passing through the smoke sampler. Because of

a high temperature, the sampler was placed 10 cm from the edge of the outlet. Smoke samples were filtered through the glass filter paper and activated carbon. Smoke samples were processed by serial devices: 1) charcoal tube, containing two sections of 0.4 to 0.8 mm of activated charcoal; desorption: solvent – benzene; 2) membrane filter; desorption: continuous extraction in a Soxhlet apparatus for 8 hr; solvent:cyclohexane. Sampling: flow rate 250 mL min^{-1}; sampling periods: 20 to 60 min. Sampling procedure was based on points 5 and 6 of ISO 9487:1991(E) 'Workplace Air-Determination of vapours aromatic hydrocarbons – Charcoal tube/solvent desorption/gas chromatografic method'. After the exposure, the samples were hermetically confined, frozen, and transported to the lab. After defrosting the samples were subject to a continous extraction with cyclohexane for 8 hr. To separate saturated hydrocarbons, cyclohexane solution was extracted with aqueous solution of N, N-dimethyl formamide. The remaining aromatic hydrocarbons were re-extracted with cyclohexane, evaporated, and the residue was dissolved in benzene. The benzene solution was analysed using gas chromatography and mass spectrometry. Samples were analysed by the GC-MS method using gas-chromatograph Hewlett-Packard Model II with EPC and capillary column HP-5MS 30 m × 0.25 mm × 0.25 μm and mass spectrometer Model 5971 Hewlett-Packard. The carrying gas – helium 1 mL min^{-1}. Conditions of chromatographical separation: feeder temperature 270 °C, detector temperature 280 °C, thermostat temperature 50 °C 5 min; 5 °C min^{-1} to 300 °C and 5 min at this temperature. The components were identified by comparing the obtained mass spectrum with the spectra in the library NBS75K.

Half of the benzene extract from each sample of the activated carbon and half of extract from each membrane filter was evaporated to constant weight and gravimetrically determined.

4. Results

4.1. Chemical composition of the smoke

Primarily, aromatic hydrocarbons produced in the process of wood burning in the kilns were identified. Also a semi-quantitative analysis of the identified groups of chemicals was possible. The following groups of aromatic hydrocarbons and their derivatives were found in the smoke samples:

a) Benzene derivatives, including dimethylbenzene, trimethylbenzene, and methylbenzene (19–38% of the total absorbed substances). Benzene derivatives are less toxic than benzene itself, they show narcotic effects.

b) Phenol and its derivatives – methylphenol, ethylphenol, dimethylphenol, methoxymethylphenol and biphenyl (7–14%)

TABLE I

Contents of carbon, nitrogen and sulphur in the study soils (collective soil samples were analysed)

	C %		N %		S %	
	control	smoky	control	smoky	control	smoky
A	4.51	4.19	0.31	0.31	0.022	0.019
B	4.32	4.78	0.43	0.36	0.039	0.021
C	5.66	5.33	0.57	0.40	0.054	0.029

A – 3 year-old charcoal kilns in forest.
B – 10 year-old charcoal kilns in forest.
C – 20 year-old charcoal kilns in forest.

c) Furan and its derivatives (heterocyclic compounds in which oxygen is the heteroatom) – dihydrofuran, methoxymethylfuran, ethylfuran, furfuryl alcohol, dibenzofuran and methylbenzofuran (0.5–2.5%)
d) Naphtalene and its derivatives (compounds with cendensed rings) methylnaphtalene, ethylnaphtalene, dimethylnaphtalene and fluorene (8–24%).
e) Policyclic aromatic hydrocarbons (PAH) – anthracene and phenanthrene (0.2–1.3%).

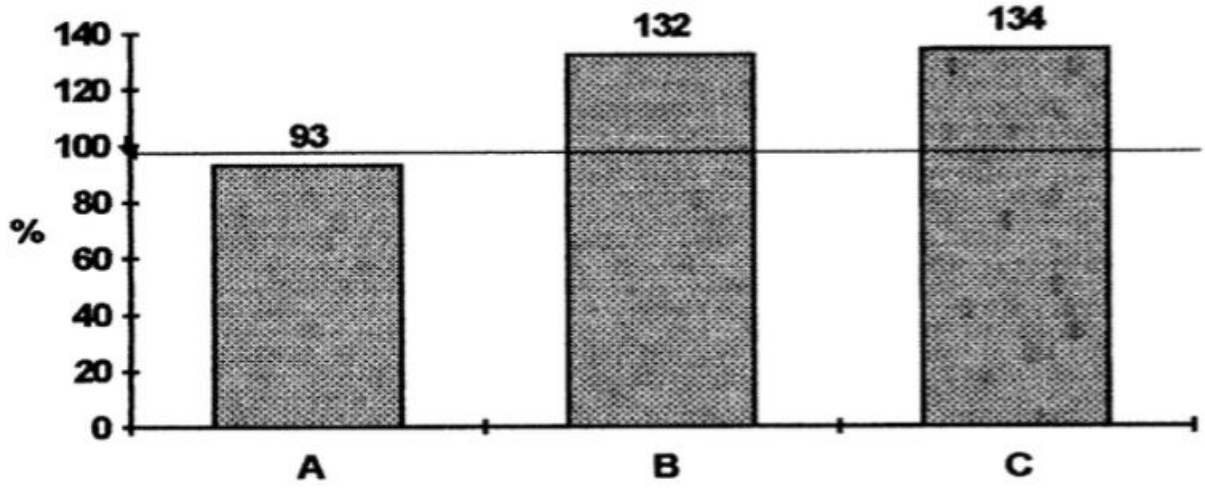
It is highly probable that also other polycyclic aromatic hydrocarbons were present in the samples, such as fluoroanthene, pyrene, benzo(a)anthracene, chrysene, and benzo(b)fluoranthene. They were not detected in this analysis because their concentrations were lower than the determination capability of the method used. Polycyclic aromatic hydrocarbons are highly harmful. They take part in metabolic processes and produce highly cancerigenous and mutagenic derivatives.

As dibenzofuran was found in the smoke samples, it is highly probable that also dioxines, chlorinated derivatives of dibenzofuran, were present. Dioxines are among the most toxic chemical compounds. They have strongly mutagenic effects, damaging the structure of the genetic code of reproducing cells.

The percentage of particular groups of compounds during charcoaling showed much variation. The content of naphtalene and its derivatives steadily declined from 24% at the beginning of the charcoaling process to 8% in the last sample. The dynamics of phenol and furan with their derivatives followed a sine curve.

4.2. Basic chemical characteristics of the soil

Biochemical properties of the soils under study are given in Maryskevich *et al.* (1997). Here we give only basic properties of the forest soils under study, such as CHNS content and pH. The contents of basic elements such as carbon, hydrogen, nitrogen and sulphur were examined only on the forest sites (Table I) because



A - 3 - years-old charcoal kilns in forest
B - 10 - years-old charcoal kilns in forest
C - 20 - years-old charcoal kilns in forest

Figure 1. Changes in C/N ratio of forest soils polluted with smoke, percentage of the control taken 100%.

they have natural, undisturbed soil structure. Soils of the open areas differed in their origin. Some were under a forest clearing and some were fallow cropland or pastures. For this reason chemical analyses were made only in forest soils. The carbon to nitrogen ratio in these soils ranged from 9 to 15. If C/N ratio in control plots is taken as 100%, the C/N ratio was higher by over 30%, except for the area where charcoal production was continued for only three years (Figure 1). In the period from three to ten years of charcoaling, the C/N ratio was then considerably changed in the area affected by the smoke.

No differences were found in the soil pH between the smoky and control areas. It ranged from 4.2 to 5.2.

The content of organic matter in the soil is shown in Table II.

4.3. Decomposition Rate

The rate of decomposition of beech leaves was relatively high as environmental conditions enhanced decomposition. The percentage loss of plant material is shown in Table III.

When the rate of leaf decomposition in the control area is taken as 100%, there was a tendency to increased decomposition rate in the smoky areas (Figure 2).

TABLE II

Contents of organic matter in the soil (% dry weight) (collective soil samples were analysed)

	A	A'	B	B'	C	C'
Control	12.7	9.11	8.64	4.03	12.2	6.71
Smoky	10.4	8.74	8.25	7.98	10.1	5.33

A – 3 year-old charcoal kilns in forest.
A' – 3 year-old charcoal kilns in meadow.
B – 10 year-old charcoal kilns in forest.
B' – 10 year-old charcoal kilns in meadow.
C – 20 year-old charcoal kilns in forest.
C' – 20 year-old charcoal kilns in meadow.

TABLE III

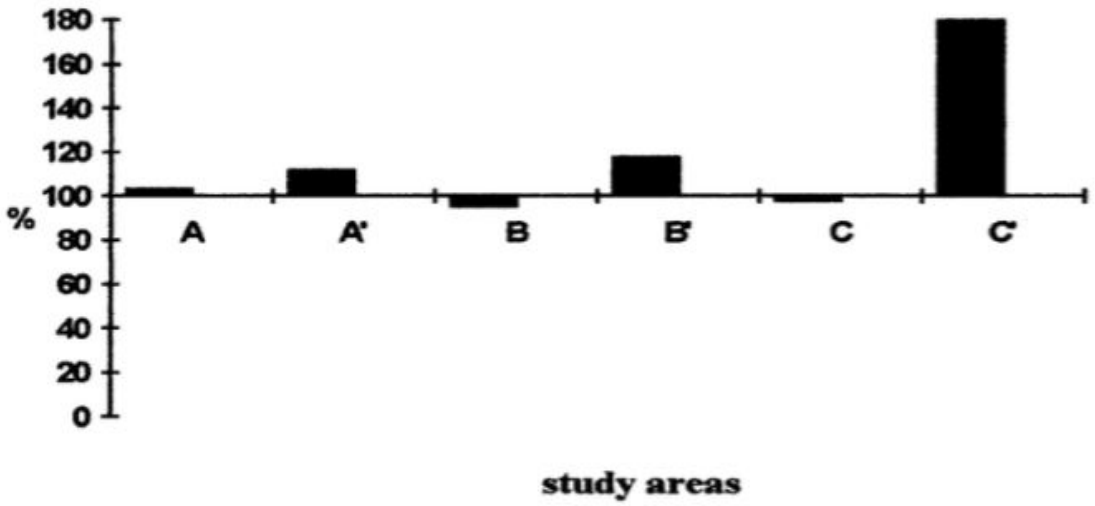
Decomposition rate of beech leaves in percentage of the initial weight (SD)

	n	A	A'	B	B'	C	C'
Control	40	54.2 (8.02)	63.2 (9.1)	52.0 (6.8)	52.4 (9.9)	62.6 (7.7)	37.1 (10.8)
Smoky	40	55.8 (4.3)	70.5 (5.7)	49.8 (9.0)	61.5 (12.0)	61.2 (5.7)	66.6 (11.4)

Description see Table II.

These differences were not statistically significant, except in area C. This tendency was clearly supported by the decomposition rate of cellulose filters (Table IV).

Percentage differences are shown in Figure 3. This figure implies that the response of forest habitats slightly differed from the response of meadows, but the general increasing trend on the smoky areas is clear and repetitive. An increase in the rate of cellulose decomposition can even be seen after 20 yr of charcoaling in the forest, whereas in the meadows the rate of cellulose decomposition declined after 10 to 20 yr of charcoaling (Figure 3). This result shows the direction of changes in the study areas, and requires a large series of investigations for its full documentation.



A - 3 - year-old charcoal kilns in forest
A' - 3 - year-old charcoal kilns in meadow
B - 10 - year-old charcoal kilns in forest
B' - 10 - year-old charcoal kilns in meadow
C - 20 - year-old charcoal kilns in forest
C' - 20 - year-old charcoal kilns in meadow

Figure 2. Differences in the decomposition rate of beech leaves among areas polluted with smoke as percentage of the decomposition rate on control areas (100%).

TABLE IV

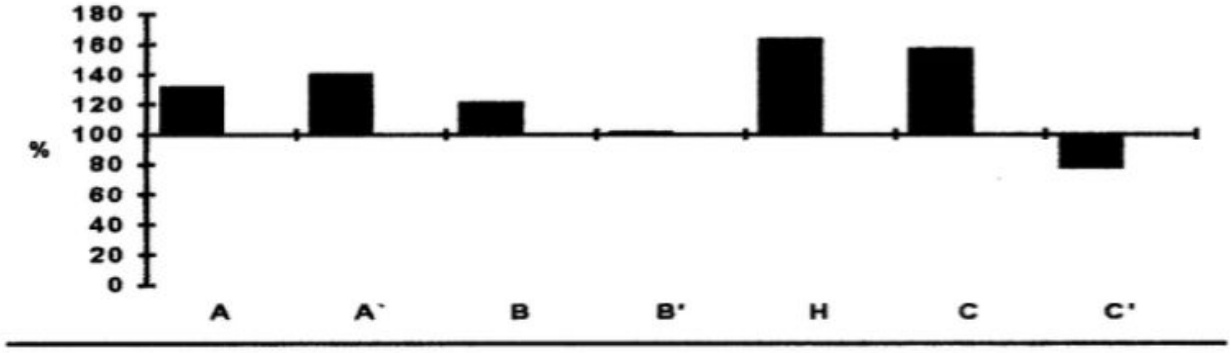
Decomposition rate of cellulose filters in percentage of the decomposed cellulose (SD)

	n	A	A'	B	B'	H	C	C'
Control	20	50.4 (20.2)	65.7 (6.7)	51.9 (11.8)	93.8 (1.4)	40.3 (14.0)	42.6 (8.3)	80.14 (25.8)
Smoky	20	56.6 (20.2)	85.4 (3.6)	62.8 (4.9)	94.5 (1.0)	65.7 (7.9)	66.7 (10.5)	62.8 (6.0)

Description see Table II.
H – 5 year-old in forest (Hylaty).

5. Discussion

To answer correctly the question raised in the Introduction, whether or not the smoke, emitted when wood is burnt under restricted air supply, can be harmful to soil systems, we would explain what we consider as a degradation of soil sys-



H-5 year-old in forest (Hylaty).

Figure 3. Differences in the decomposition rate of cellulose filters among areas polluted with smoke, calculated as percentage of the decomposition rate on control areas taken as 100%.

tem, and why the rate of organic matter decomposition was considered here as a degradation index.

As it is known, each ecological system has self-regulatory mechanisms. It is assumed that in the situation when self-regulation is insufficient, the ecological balance is disturbed. Each ecological system, including soil systems, is subject to more or less natural transformations leading to its adaptation to environmental conditions through self-regulatory mechanisms.

It is theoretically assumed that a soil system is balanced when the matter and energy inflow is balanced by outflow. Thus, the balance is disturbed when the decomposition rate of dead organic matter is either reduced or increased (Fischer and Marchwińska, 1990).

Decomposition of organic matter is the basic energy stream leaving the system. Disturbance can take place through reduction or enhancing the inflow of dead organic matter to soil. Quantification of these variables is very difficult because usually the research is limited to indices of directions of changes.

Based on these assumptions, an attempt was made to examine directions in the rate of energy release from the soil system, that is, in the rate of decomposition of dead organic matter, to estimate the possible range, or tendency, of the disturbance to the balance of the basic ecological system such as the soil.

Pietr *et al*. (1995) have found that the decomposition rate of plant organic matter and pure cellulose in the form of filters is a very sensitive index of environmental factors. They analysed the rate of decomposition of cellulose filters and plants predominant in the Sudetes, and they found significant correlations, primarily between the decomposition rate of organic matter and the nitrogen content in the soil, and between the decomposition rate of cellulose filters and the carbon/nitrogen ratio in

the soil. A recalculation of the data from the Carpathians Mountains confirmed all the relationships found in the Sudetes, the only difference being that the decom-

position rate in the Karkonosze was considerably lower than in the Carpathians. Among other things, this was a result of an extremely heavy degradation of the habitat of the Karkonosze.

Thus, it has been found that the increased decomposition rate of cellulose filters in smoky areas can be related to the increased carbon to nitrogen content ratio in the soil. The fact that the decomposition rate of organic plant material did not respond so strongly as did the decomposition rate of pure cellulose can imply that nitrogen was an important factor in the smoky areas, where typically the content of nitrogen is lower (Table I). As stated in the Introduction, the rate of decomposition is an index of a net outcome of different processes, and the results obtained are only a final effect of a better or poorer functioning of the soil system.

A question arises whether the increased decomposition rate of cellulose filters can be considered as an index of the degradation of the soil system or, on the contrary, of the improvement of its condition? The composition of the smoke polluting natural systems is a typical example of the inflow of energy from allochtoneous chemical compounds, mostly decomposable. It should be remembered, however, that although such emission does not reduce decomposition rate immediately, like lead or cadmium, it is not indifferent to the natural environment. After some time of the increased decomposition rate, the duration of which is difficult to determine, the soil system enters a critical state. A period of dangerous oscillation comes, accounting for an abrupt break-down of living processes (Odum, 1982; Fischer and Bieńkowski, 1984; Fischer and Marchwińska, 1990).

Based on Table IV and Figure 3, a question arises whether after 20 yr of charcoaling in the open area (site C), the soil system came to such a break-down? Keeping in mind that we analysed only kilns selected as examples in specified habitats, that in addition differed in the duration of their work (3–20 yr), the conclusions must be considered with caution. A complex statistical analysis of the results of the studies of this kind may often be useless as the natural variation in soil systems is large. Statistical analysis was used for the same material in laboratory studies (Focht, in press; Uvarov, in press). Thus, the present analysis is limited to clearly cut differences and tendencies. The most important conclusion of this work is that the smoke from charcoal kilns is not indifferent. It seems that the harmful effects of smoke on the surrounding natural environment could be largely reduced by controlling the time of charcoaling in a single place.

6. Conclusions

1. Smoke emitted from charcoal kilns contains large amounts of aromatic hydrocarbons such as benzene, phenol, furan, naphtalene and numerous policyclic aromatic hydrocarbons.

2. Smoke emitted from charcoal kilns under restricted air supply is not indifferent to soil systems exposed to it.

3. The intensity of soil metabolism – biological activity – is increasing during a long-term exposure to smoke, which is one of the indications of anthropogenic disturbance resulting from organic factors.

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