THE EFFECT OF SMOKE FROM CHARCOAL KILNS ON SOIL RESPIRATION

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Abstract. The objective of the work was a laboratory examination of the effect of a water-soluble fraction of the smoke, emitted during charcoaling by dry distillation, on soil metabolism. The experimental soil was exposed to smoke for ten years and the control soil was taken from a site not exposed to smoke. Oxygen uptake and carbondioxide evolution were measured in soil samples by using the method of volumetric respirometry. When an aqueous smoke solution was added to the soil, the rate of oxygen metabolism increased by a factor 15 for the experimental soil and by a factor 5 for the control soil. A similar increase was observed in carbondioxide evaluation. RQ was clearly higher for the experimental soil. Also after the addition of an aqueous smoke solution to the soil, differences were observed in changes of RQ between the experimental and control soils. These differences suggest that respiratory metabolism is changed in the soils permanently exposed to smoke, and RQ value can be an indicator of the initial stages of soil degradation.

Keywords: smoke, soil degradation, soil respiration

1. Introduction

The Western Carpathians support the only extensive complex of natural beech forests and mountain meadows in Europe. The traditional charcoal production in this area, performed by the method of burning under restricted air supply, goes back to the XV-th century (Augustyn *et al.*, 1995).

Nowadays charcoaling is conducted in steel kilns with several smoke outlets in the upper part. Especially at the beginning of charcoal kilning, the emitted smoke is heavy, spreading all around depending on the configuration of the area and wind direction. A question arises whether and in which way this smoke affects the functioning of ecological systems.

Since soil is a basic component of many ecological systems and at the same time has a high capacity for accumulating different pollutants, it was decided to examine the effect of water-soluble smoke fractions on the respiratory activity of the soil.

2. Material and Methods

Soil samples were taken from an area exposed to the smoke emitted by a charcoal kiln for ten years, containing gases and water-soluble compounds falling with precipitation or mist. This area was situated in a ravine with a stream flowing to the river San. It was covered with a beech (*Fagus silvatica*) forest with an admixture of the silver fir (*Abies alba*). Soil with a large admixture of stones derived from the underlying sandstone was covered with a thin layer of humus.

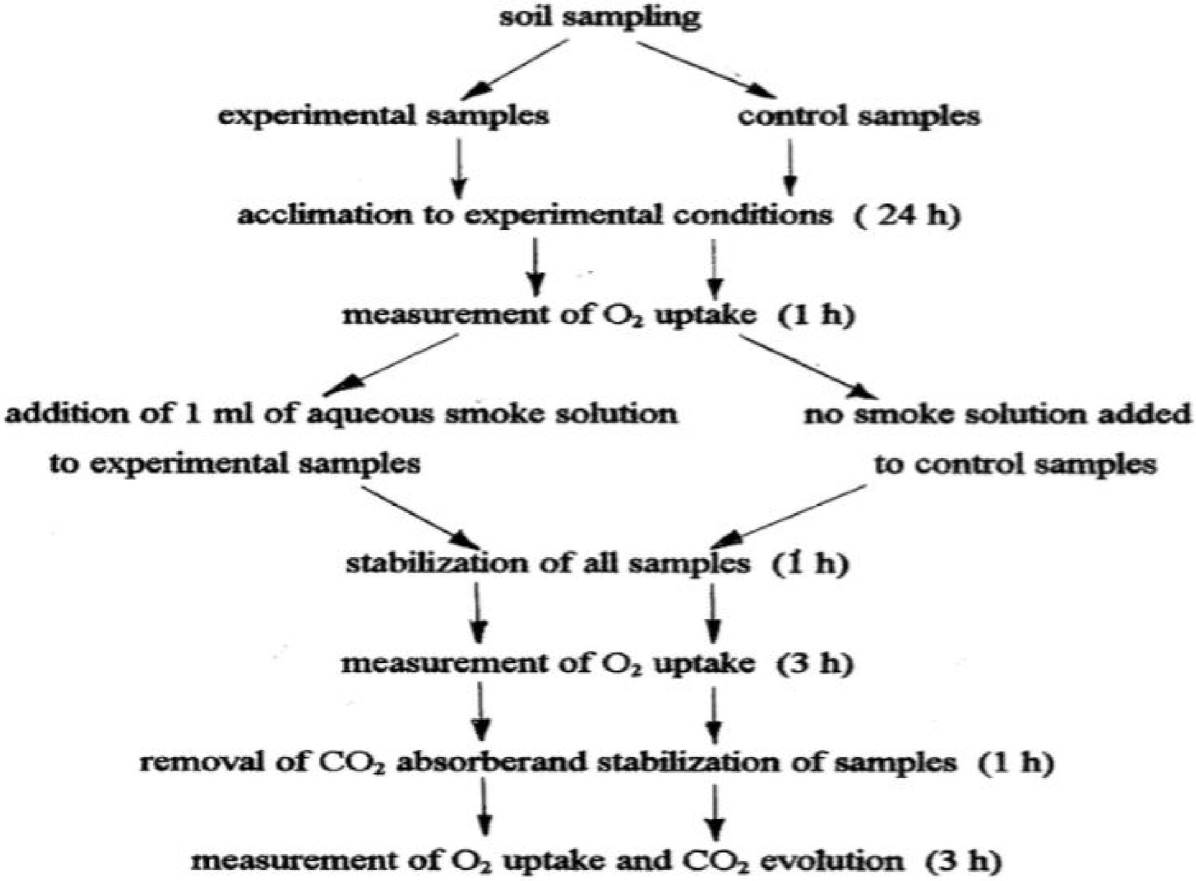
Control soil samples were taken from the area also supporting the Carpathian beech forest with an admixture of fir (*Dentario glandulosae – Fagetum*) that has never been subjected to economic activity of any kind. Experts considered these two areas as identical in terms of their phytosociological characteristics (T. Winnicki pers. comm.)

The solution of the water-soluble fraction of the smoke from the charcoal kiln used in the experiment was obtained by collecting the smoke through a plastic funnel from one of the side outlets of the kiln and passing it through a series of 3 washers containing 100 ml of distilled water each using a vacuum pump. After 2 hours about 1 litre of the solution was collected. The smoke contains 80 – 90% of water vapour. The obtained solution contained about 20 g of organic substances emitted to the surroundings. The content of organic, water soluble fraction in the collected volume of water was estimated basing upon the oxygen consumption from bichromate (COD) and expressed in mg cresol per litre. Beside smoke substances dissolved in water, a considerable proportion of oily and tar material (presumably of higher molecular weight) was deposited on walls of the washer series and connecting tubes. The list of substrances found in smoke was given by Fischer and Bieńkowski (in press). Since soil samples were treated with aqueous smoke solution, low-molecular compounds dissolved in them prevailed. Compounds of higher molecular weight were deposited on the walls as tar, whereas their content in the solution was low.

Soil cores (about 3 kg) were transported to the laboratory and placed in about 0,5 kg – containers in a climatic chamber at 15°C. Soil moisture was set at about 50%. Water losses were complemented with distilled water.

From the soil preserved in this way, ten samples of 12 – 13 g each were taken to measure the metabolism by using a method of volumetric respirometry (Klekowski, 1975). Oxygen uptake was measured after 24 hours since the time of soil removal from the container so that oxygen uptake could stabilize, then seven samples were treated with 1 ml of the solution of water-soluble smoke fraction from the charcoal kiln, and three others were left untreated for comparison. Distilled water was not added to control soil samples because a pilot study showed no effect of additional water on the results. One hour later, oxygen uptake was measured again in all the samples. Then, after the removal of the carbon dioxide absorbent (25% NaOH) and a one-hour break for stabilization of the system, CO_2 evolution was measured.

The sequence of measurements is shown in Scheme 1.



Scheme 1.

The measurements were continued for 5 days and after a 2-day break for the next 5 days. Every day the oxygen uptake was measured for samples with smoke added and for control not treated with the solution of water-soluble fraction of smoke from the charcoal kiln. On days 1,2,5 and 12 also the evolution of carbon dioxide was measured. A total of two 12-day series of measurements were taken for each of the two soils (that is, 5 days of measurements, 2-day break, and 5 days of measurements). In sum, there were 337 measurements of the oxygen uptake for soils with smoke solution added and 124 measurements for soils without smoke solution, 119 measurements of CO_2 evolution from the soil with smoke solution, and 36 measurements of CO_2 evolution from the soil without smoke solution.

After the measurements were taken, the soil samples were weighed, dried for 3 hours at 105°C, then weighed again to determine moisture content, and ignited in a muffle furnace at 450°C. The ash was weighed to determine the content of

TABLE I

Oxygen uptake by the soil from the smoke-exposed site and from the control site, treated and not treated with smoke sollution on succesive days of the experiment (in $\mu l\ O_2/h$ g org. mat. $\pm$ SD)

Type of soil	Soil from the smoke-exposed site		Soil from the control site	
Days of experiment	Soil after addition of smoke solution	Control soil	Soil after addition of smoke solution	Control soil
0 state before addition of smoke solution	7.79 ± 1.15	3.47 ± 2.18	5.67 ± 0.76	5.63 ± 0.84
1	91.89 ± 4.03	5.28 ± 1.69	29.90 ± 1.49	4.39 ± 0.42
2	46.50 ± 6.42	12.93 ± 6.37	22.54 ± 1.87	7.77 ± 0.88
3	33.80 ± 3.01	11.65 ± 3.90	27.18 ± 1.99	5.71 ± 0.86
4	51.76 ± 4.28	20.47 ± 9.07	47.21 ± 2.86	4.76 ± 0.24
5	150.84 ± 40.15	9.16 ± 3.43	64.92 ± 5.04	5.89 ± 2.13
8	89.49 ± 4.81	11.59 ± 3.74	52.44 ± 6.22	5.50 ± 1.13
9	63.38 ± 4.51	16.02 ± 3.05	35.91 ± 4.64	5.19 ± 0.14
10	46.23 ± 4.67	16.61 ± 4.29	21.56 ± 1.96	3.89 ± 0.28
11	44.01 ± 5.65	19.78 ± 5.03	17.71 ± 2.24	5.44 ± 0.92
12	35.26 ± 4.65	20.52 ± 7.19	17.13 ± 2.51	5.24 ± 0.35

In total, 337 measurements of oxygen uptake were taken after the addition of the soluble smoke fraction, and 124 measurements for the control soil.

organic matter. The amount of oxygen taken and carbon dioxide evolved has been calculated per gram of organic matter content in the soil.

3. Results

The soil taken from the control site, without addition of the aqueous smoke solution, used about 5 $\mu l\ O_2$ per hour per 1 g organic matter over the whole study period (Table I). A similar oxygen uptake was recorded for the soil taken near the charcoal kiln, but only at the beginning of the experiment. Later it fluctuated about 20 $\mu l\ O_2$ per h per g organic matter, which may imply that the stability of metabolic processes was disturbed in the soil permanently exposed to smoke for 10 years.

After the addition of 1 ml of aqueous smoke solution to soil samples, oxygen uptake rapidly increased, reaching after one hour a level higher by a factor of 5 as compared with that of the soil from the control site, and higher by a factor of 15 as compared with the original value for the soil from the charcoal kiln surroundings.

TABLE II

CO_2 evolution from the soil taken from the smoke-exposed area and from the control area treated and not treated with smoke solution on succesive days of the experiment (in μl CO_2/h g organic matter ± SD)

Type of soil	Soil from the smoke exposed site		Soil from control site	
days of experiment	soil after addition of smoke solution	control soil	soil after addition of smoke solution	control soil
1	59,28 ± 8,41	5,00 ± 1,62	20,43 ± 2,66	–
2	33,75 ± 5,61	12,16 ± 6,52	16,24 ± 1,83	5,26 ± 0,60
5	87,08 ± 12,49	2,27 ± 1,47	50,30 ± 6,58	2,49 ± 1,32
12	40,12 ± 5,15	19,83 ± 5,07	16,17 ± 2,23	3,44 ± 0,72

In total, 119 measurements of CO_2 evolution from the soil were taken after the addition of the soluble smoke fraction, and 36 measurements for the control soil.

On the second and third days, oxygen uptake rapidly declined to about 30 μl per h per g organic matter. During the next days, oxygen uptake increased again. The highest recorded oxygen uptake reached 192 μl O_2 per h per g organic matter for the soil from the charcoal kiln surrounding and 77 μl O_2 per h per g organic matter for the soil from the control site. This peak occurred on day 5 after the treatment of soil samples with the aqueous solution of soluble fractions of the smoke from the charcoal kiln. On day 8, the oxygen uptake declined to 92 μl for the soil from the charoal kiln surroundings and to 61 μl for the soil from the control site. Over the next four days, oxygen uptake declined and gradually approached the level characteristic of the control soil without aqueous smoke solution.

The pattern of CO_2 evolution was similar to that of oxygen uptake. The initial increase in CO_2 evolution was followed by a decline and then by a considerably higher increase about day 5 of the experiment (Table II). Afterwards it gradually declined to the level close to that recorded for control samples.

Based on the oxygen uptake and CO_2 evolution, the respiratory quotient RQ was calculated, that is, the ratio of the amount of CO_2 evolved to the amount of O_2 taken by the soil. This index is mostly used in animal physiology to characterize the condition of an organism, but it is also used for characteristics of ecological systems (Fischer 1995). The value of RQ showed considerable diferences between the soil from the charcoal kiln surrounding, exposed to the smoke and the soil from the control point (Table III). RQ of the soil permanently exposed to the smoke was higher than RQ of the soil from the control site. Identical changes in RQ were observed in the control soil after the addition of smoke solution. Differences were recorded in the response to the added smoke solution between the soil permanently exposed to smoke and the control soil. RQ of the former decreased whereas that

of the latter increased, which may imply differences in the mechanisms of the response.

TABLE III

The value of RQ for the soil from the smoke-exposed site and from the control site, treated and not treated with smoke solution (× ± SD)

Type of soil	Soil from the smoke exposed site		Soil from control site	
days of experiment	soil after addition of smoke solution	control soil	soil after addition of smoke solution	control soil
1	0,63 ± 0,31	1,00 ± 0,01	0,70 ± 0,38	–
2	0,68 ± 0,12	0,80 ± 0,40	0,70 ± 0,15	0,68 ± 0,12
5	0,82 ± 0,32	1,00 ± 0,01	0,74 ± 0,23	0,49 ± 0,66
12	0,80 ± 0,16	0,83 ± 0,24	0,72 ± 0,13	0,60 ± 0,22

4. Discussion

The soil, which is a hibitat of many kinds of bacteria, fungi, Actinomycetes, protozoans and other small organisms, shows specific responses to different chemicals commonly called pollution. A good index of this response is the rate of oxygen metabolism (Weber, 1985; Schroeder and Urban, 1985; Bieńkowski, Fischer and Goździewicz, 1986). Heavy metals toxic to cell metabolism strongly inhibit soil respiration (Delman and Haanstra, 1979), but because of a huge diversity of soil bacteria, different chemicals can be assimilated by them or used a respiratory substrate. As a result, only a small change in the level of respiration can be observed (Cronan, 1985; Fritze *et al.*, 1992) or even a considerable increase in this level when the substances penetrating the soil are used by bacteria at a high rate. The latter seems to provide explanation for the result of the experiment. The water-soluble fraction of the smoke emitted from charcoal kilns mainly contains low-boiling organic compounds of the type of alcohols (2–4%), low-molecular fatty acids C1 – C4 (6–10%), high-boiling organic compounds of the type of soluble tar (4–9%) partly precipitating from the aqueous solution, and 78–88% of water (Shaburov, 1984). All these compounds, except for water, can be consumed by strains of prototrophic bacteria occurring in the soil. Typically, they are not abundant but in the habitats with a permanent inflow of nutrients such as methanol, phenol, aliphatic short chain or alicyclic hydrocarbons they may occur in large numbers (Kunicki-Goldfinger, 1971). Just these bacteria can be responsible for the increase in oxygen uptake by the soil treated with an aqueous solution of smoke, and for change in the value of RQ calculated for the soil. When the bacteria used up the nutrients added in a limited amount, the oxygen uptake decreased to the level typical of the soil not treated with smoke solution. Presumably, in the natural

habitat of the Western Carpathians, these bacteria clean the soil from hydrocarbons emitted by charcoal kilns. These bacteria must be more abundant near charcoal

kilns because of a permanent substrate inflow. In the nature reserve they are less abundant, though also present, as confirmed by an increase in respiration, after the addition of smoke solution, also recorded for this soil, though not so high as for the soil from the chararcoal kiln surroundings. Metabolizing of these compounds leads to an increased production of carbon dioxide, this being also recorded in the experiment.

Carbon compounds contained in the smoke can be used as food by soil microorganisms as indicated by the immediate change in the respiratory quotient RQ of the soil treated with smoke solution.

The occurrence of these prototrophic bacteria accounts for neutralization of alien substances penetrating the soil, precluding their excessive accumulation and the subsequent degradation of the soil. For this reason, it seems that although charcoaling is not indifferent to the soil, it is not necessarily degrading the soil if some safety thresholds are not exceeded. If they are exceeded, the system can not be restored. A warning signal here is a large difference in the value of RQ between the soil exposed to smoke from the charcoal kiln and the soil from the control site. Also the change in RQ after the addition of smoke solution to the soil was different – RQ declined in the soil from the charcoal kiln surroundings, whereas it increased in the soil from the control site, not exposed to smoke. Such differences are typically indicative of a change in the meachanism of the response of a system that might have been caused by the ten-year long action of the smoke (Fischer and Bieńkowski, 1984; Fischer and Marchwińska, 1990; Fischer and Mienshutkin, 1997).

5. Conclusions

1. The smoke emitted from charcoal kilns is not indifferent to the soil.
2. It clearly intensifies respiratory metabolism of the soil.
3. The intensification of respiration is higher in the soil earlier exposed to substances contained in the smoke, whereas lower in the soil not exposed to smoke, which may be indicative of adaptational changes.
4. The respiratory quotient RQ is higher in the soil permanently exposed to the smoke than in the soil not exposed to the smoke. The response of these two kinds of soils to the aqueous smoke solution largely differ, which may be indicative of changes in soil mechanisms after long-term smoke action. The respiratory quotient RQ can be used as a comparative index of the threat of soil degradation.

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