Impact of farming intensity reduction in the Šumava foothills region on changes in soil organic matter and surface water quality

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ABSTRACT

Samples of soils and surface waters were analysed in the Šumava foothills region in nine watersheds with an area 78.5 km^2 in 1986–1987 and in 2001. Lower intensity of fertilization and liming and other changes in Czech agriculture were found to result in a decrease in the content of cold and hot water soluble carbon (C_w and C_{hws}) in the soil; the content of biologically decomposable matter expressed as BOD_5 and BOD_t of water extract of soil also decreased. The values of rate constants k of BOD kinetics of soil suspension indicate that the most valuable fast decomposable organic matter in the soils of this region have practically been mineralized to HCO_3^-, which are gradually eluted from soils and their increased amounts are present in surface waters. On the contrary, the transport of N-NO_3^- decreased to 66.3% of the value in 1986, that of N-NH_4^+ to 7.1% while the ratios C:N and N:P increased as a result of lower P elution in relation to lower N elution. COD_{Mn} showing the proportion of readily decomposable matter increased. A decrease in conductivity, i.e. in the content of dissolved salts in waters, was highly significant. These results warn against an optimistic interpretation of surface water analyses that indicate positive impacts of farming intensity reduction on the landscape. The results in the Šumava foothills region demonstrate that a major part of the most valuable components of soil productivity, decomposable organic matter, has already been decomposed, so their content in the soil has decreased. Natural sources (roots, root exudates, plant residues) are not able to ensure an equilibrium balance of these valuable matters at a lower farming intensity.

Keywords: organic matter; relationship between soil and surface waters; interpretation of analyses; changes in farming intensity; watershed

Political changes in the Czech society in the last twelve years have been markedly reflected in landscape management.

Conversion of arable land to grasslands and pastures has been effectuated on a large scale, a decrease in cattle stocks has been enormous, and that is why forage crops have disappeared from crop rotations. Crop rotations are subordinated to market economics, the traditional sequence of crops is not used any longer, and on the other hand, the proportion of industrial crops, mainly rape, has increased. Fertilizer inputs into the soil have markedly decreased under economic pressures and due to lack of organic fertilizers.

In 1986 nine watersheds ranging from 4.900 km^2 to 16.838 km^2 in size were chosen in the area where former Šumava State Farms pursued their agricultural activities: the area is demarcated by the communes Trhové Sviny, Český Krumlov and Rožmitál in Šumava (Český Krumlov district and south-eastern part of České Budějovice district). The impacts of agricultural activities on water quality were investigated in these agricultural areas from chemical and hydrobiological aspects (Gergel et al. 1989).

After fifteen years, these investigations were repeated to find out what happened in the Šumava landscape as a result of the above-mentioned changes in agriculture.

The composition of surface waters in this area depends on elution processes that are influenced by sorption and desorption characteristics of soils. Variations in these characteristics are related to the use of agricultural land, i.e. cultivating practices, fertilization, liming and changes in microbial activity. These changes in the Šumava region were described in detail in our previous papers (Kolář et al. 2000a, b).

MATERIAL AND METHODS

We carefully used the same methods as in 1986 in the course of our investigations.

Table 1 shows the basic characteristics of the watersheds under study. Sampling profiles were precisely localized with the apparatus Garmin eTreex.

Hydrochemical characteristics were measured regularly every fortnight.

These characteristics were determined in accordance with the standard ČSN 83 0530: pH, $KNK_{4.5}$, $ZNK_{8.3}$, permanganate demand, ammonia and ammonium ion, nitrates, phosphates, calcium, potassium, magnesium, sulfates, chlorides, specific electrolytic conductivity, solutes and undissolved substances in dry matter. Total

Table 1. Basic characteristics of the watersheds under study

Sample	Stream	Area (km^2)	Forest percentage (%)	Altitude above sea level (m)	Climatic region	Specific outflow ($1/s/km^2$)
101	Malý Strážný	6.035	20	630–750	B10	8.59
102	Sušský	13.323	30	600–830		8.59
103	Práčovský	8.153	30	510–650	B10	10.59
104	Močeradský	7.308	30	630–800	B10	7.82
105	Zdíkovský	16.963	40	570–770		7.40
106	Zvíkovský	6.992	30	480–610		9.61
107	Buďský	7.111	30	490–690	B10	9.61
108	Popelicko-Dluhošťský	7.779	60	580–770	B10	11.34
109	Kondračský	4.900	20	490–630	B10	6.18

phosphorus was determined in accordance with the standard ČSN 83 0550. Nitrite nitrogen was not a part of calculations in the determination of inorganic nitrogen due to its very small amount. Nutrient ratios were calculated from inorganic carbon [($KNK_{4.5}$ + $ZNK_{8.3}$).12] and inorganic nitrogen (N-NH_4^+ + N-NO_3^-). Total phosphorus was considered in nutrient ratios. We are aware of the inaccuracy of C calculation from CO_2 concentration from the sum of $KNK_{4.5}$ and $ZNK_{8.3}$ that is feasible only if the carbonate buffering system is dominant in water and the concentration of total CO_2 is higher than 0.5 mmol.l^{-1}. However, comparative measurements were used in this case.

Saprobity was determined pursuant to the standard ČSN 83 0532 from April and October samplings (Sládeček et al. 1980).

Table 2. Water analyses

	Sample	pH	$KNK_{4.5}$	$ZNK_{8.3}$	NRLs	RLs	N-NO_3^-	N-NH_4^+	P_{total}	COD_{Mn}	Conductivity	C/N	N/P
			(mmolequiv/l)				(mg/l)				(mS/m)		
2001	101	7.70	2.02	0.14	20.70	253.10	5.32	0.020	0.135	4.90	35.5	5.07	79.04
	102	7.51	0.58	0.11	22.10	122.20	4.03	0.000	0.115	6.07	15,4	2.07	62.37
	103	7.57	1.04	0.12	24.90	178.70	5.02	0.005	0.141	6.24	22.5	2.82	53.42
	104	7.45	0.64	0.10	18.60	118.20	3.08	0.000	0.121	5.69	14.5	2.99	44.73
	105	7.31	0.80	0.14	16.00	132.10	3.35	0.070	0.136	7.11	15.1	3.37	41.29
	106	7.36	0.98	0.13	21.50	275.20	9.53	0.008	0.130	5.53	27.8	1.45	103.47
	107	7.31	0.70	0.11	27.80	188.20	6.89	0.004	0.103	5.24	23.9	1.44	163.49
	108	7.26	0.70	0.16	43.10	138.10	2.72	0.007	0.115	5.69	16.2	3.91	39.29
	109	7.22	0.80	0.10	14.90	193.60	5.42	0.024	0.115	6.69	23.5	2.37	102.73
	average	7.41	0.92	0.12	23.29	177.71	5.04	0.015	0.123	5.91	21.60	2.83	76.65
	standard deviation	0.15	0.41	0.02	7.97	53.57	2.03	0.02	0.01	0.66	6.68	1.11	38.52
	V%	2.02	45.18	15.76	34.24	30.14	40.18	136.00	9.66	11.13	30.93	39.26	50.26
1986	101	7.60	0.11	1.47	13.77	262.77	7.46	0.148	0.120	3.88	29.30	2.49	63.39
	102	6.97	0.07	0.30	9.54	182.77	6.16	0.218	0.140	4.89	171.59	0.7	45.59
	103	7.28	0.09	0.65	12.15	276.77	9.11	0.367	0.210	5.06	246.97	0.94	45.14
	104	7.09	0.07	0.36	30.08	168.00	3.84	0.195	0.100	4.26	128.19	1.28	40.38
	105	7.29	0.08	0.43	9.08	178.62	3.98	0.250	0.120	5.45	140.71	1.45	35.24
	106	7.14	0.14	0.81	20.31	438.92	9.40	0.133	0.160	4.79	302.14	1.2	59.57
	107	7.03	0.07	0.30	13.31	293.23	12.03	0.133	0.160	4.03	274.23	0.37	76.01
	108	7.11	0.08	0.41	12.62	172.31	5.36	0.211	0.120	4.67	160.93	1.06	46.39
	109	7.05	0.09	0.50	9.92	343.23	11.06	0.234	0.130	6.67	400.42	0.63	86.9
	average	7.17	0.09	0.58	14.53	257.40	7.60	0.21	0.140	4.86	206.05	1.12	55.40
	standard deviation	0.17	0.02	0.33	6.02	83.07	2.67	0.07	0.03	0.76	99.06	0.55	15.53
	V%	2.40	23.30	57.41	41.43	32.27	35.18	31.18	20.95	15.57	48.08	48.97	28.04

V = coefficient of variation

Dried mixed samples of topsoils taken in accordance with the principles of soil analyses (SA) were available from 1986 (spring) from the watersheds of several streams only: Močeradský, Buďský, Popelicko-Dluhošťský, Zvíkovský and Kondračský (104, 106, 107, 108 and 109). This is the reason why samples from the topsoil layer were taken solely in these watersheds in 2001. According to SA, mixed soil samples from the particular watersheds should represent sets of 92–261 units per watershed. Unfortunately, collection samples from 1986 were missing from some localities, so the numbers of samples were lower. Methods of analytical determinations were described in detail in 2000 (Kolář et al. 2000a, b).

Readily soluble organic carbon compounds are naturally the most reactive in biochemical processes in soils; water-soluble carbon C_w in the soil determined in an extract of 0.01 M $CaCl_2$ is important for assessment of many processes influencing the soil productivity (Vaněk et al. 1997).

Degradability of organic matter in soil samples was tentatively evaluated after standard inoculation of dried samples with fresh topsoil suspension and after preincubation.

Biologically decomposable organic matter in the soil is so important for transformation through mineralization and humification, and for the biological activity of soil and general potential productivity of soil, that we decided to prepare 1% soil suspensions of collected soil samples in water and to study the organic part of these systems by means of biological oxygen demand over 5 days (BOD_5) and total biological oxygen demand (BOD_t) as it is usual in hydrochemical analytics. Instead of traditional Winkler's method an oxygen electrode with oxygenmeter OX 4-1 (Chirana) was used for oxygen determination. BOD is defined as an amount of oxygen consumed by microorganisms for biochemical oxidation (mineralization) of organic matters under aerobic conditions and without the co-action of photosynthesizing microorganisms. The consumed amount is proportionate to an amount of the present decomposable organic matter (Pitter 1981). A traditional dilution method was used. Most authors state that BOD kinetics is guided by the first-order reaction kinetics:

$$\frac{dy}{dt} = KL_r = K(L - y)$$

where: L = total BOD
L_r = residual BOD
Y = BOD in time t
K = rate constant

The equation for BOD in time t is obtained by integration from 0 to t and by further calculation: $Y = L\,(1 - 10^{-kt})$

Rate constant k is variable and it is a better way of expressing the quality of decomposable organic matters than BOD_5. The value of k is e.g. for glucose 0.87/day and for peptone 0.74/day at 20°C, the values below 0.1/day indicate less readily decomposable organic matters.

The value of BOD_t is calculated from several values of BOD determined experimentally in shorter time intervals; the data are processed according to the equation for the first order kinetics (Tuček et al. 1977).

The procedures reported by Eckschlager (1971) were used for mathematical and statistical evaluation of the results. The interval of reliability $(1 - \alpha) = 0.95$ was calculated from the equation $L_{1,2} = x \pm t.s_x$.

RESULTS AND DISCUSSION

Table 2 shows average values for all studied streams in 1986 and 2001.

Saprobity index is illustrated in Figure 1 showing that water quality improved in spring in comparison with 1986, but it was a slight improvement only.

A decrease in nitrate nitrogen to 66.3% and ammonium nitrogen to 7.1% of the 1986 level is very positive. On the other hand, the value of chemical oxygen demand COD_{Mn} indicating the proportion of readily decomposable organic matters increased.

The ranges of C:N and N:P ratios increased. In the former ratio, there was an increase in the transport of in-

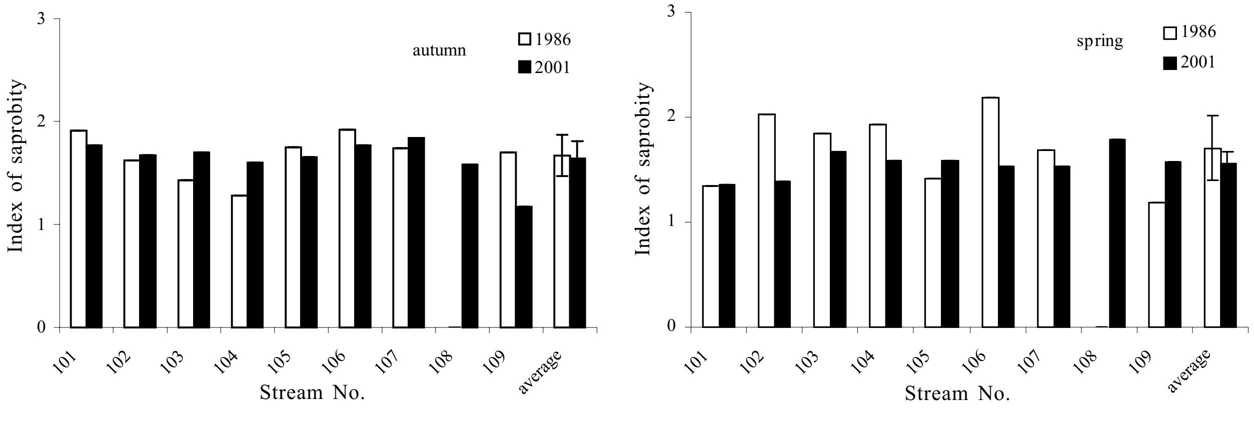

Figure 1. Saprobity of the tested streams in 1986 and 2001

Table 3. Analyses of soils in the watersheds, pH_{KCl}, total organic carbon C_{org}, active organic carbon C_{hws}, water-soluble carbon C_w, degree of humification D_H, humic acids to fulvic acids ratio HA:FA, nitrification test t_{NIT}, carbon of basal respiration C_{BR}, microbial biomass carbon C_{MB}, Hendrix's index of biological activity of soil H_{BAS}

	Sample	Number of samples	pH_{KCl}	C_{org} (%)	C_{hws} (mg/1000 g)	C_w (mg/1000 g)	S_H (%)	HK: FK	t_{NIT} (mg/1000 g)	C_{BR} (mg C/1000 g dry matter/day)	C_{MB} (mg/1000 g)	$H_{BAS}.10^3$
2001	104	42	6.25	2.42	240 ± 25	84 ± 45	18	0.83	21 ± 4	12 ± 3	420 ± 90	28.6
	106	30	6.17	2.55	276 ± 32	55 ± 33	10	0.72	12 ± 3	20 ± 2	560 ± 70	35.7
	107	24	6.28	2.16	210 ± 25	118 ± 48	15	0.75	16 ± 4	11 ± 2	500 ± 120	22.0
	108	34	6.31	2.10	203 ± 21	74 ± 41	19	0.88	8 ± 2	18 ± 3	605 ± 190	29.8
	109	14	6.14	2.31	185 ± 24	51 ± 30	17	0.64	10 ± 3	5 ± 1	400 ± 140	12.5
	average	–	6.23	2.31	223 ± 25	76 ± 39	16	0.76	13 ± 3	13 ± 2	500 ± 120	25.7
1986	104	42	6.18	2.40	283 ± 27	120 ± 58	18	0.85	26 ± 6	21 ± 5	550 ± 150	38.2
	106	30	6.15	2.57	291 ± 32	98 ± 53	9	0.70	22 ± 5	19 ± 4	600 ± 170	31.7
	107	24	6.23	2.12	205 ± 24	103 ± 41	14	0.73	24 ± 5	18 ± 5	500 ± 210	36.0
	108	34	6.20	2.15	240 ± 30	95 ± 55	20	0.85	15 ± 4	24 ± 5	600 ± 150	40.0
	109	14	6.15	2.20	210 ± 22	60 ± 37	18	0.65	11 ± 3	14 ± 3	620 ± 170	22.6
	average	–	6.18	2.29	246 ± 27	95 ± 49	16	0.76	20 ± 5	19 ± 5	575 ± 170	33.7

organic carbon from the watershed (155.5%), in the latter ratio a decrease in nitrogen content was faster than a decrease on the content of total phosphorus.

Table 3 shows the results of soil analyses: variations in C_{org}, C_w, C_{hws}, HA:FA ratio, humification degree, nitrification test t_{NIT} (Kubát and Voplakal 1994), carbon of basal respiration C_{BR}, microbial biomass carbon C_{MB}, index of biological activity of soil according to Hendrix et al. (1989). To determine t_{NIT}, C_{BR} and C_{MB} the samples were inoculated with an admixture of 2% standard live topsoil.

It is evident from Table 3 that in 2001, in comparison with 1986, pH_{KCl} slightly increased, C_{org} content did not practically change if evaluated in percents, active soil carbon C_{hws} decreased, water-soluble carbon C_w also decreased, but this decrease was statistically insignificant due to its high variability. The degree of humification D_H did not change, neither was there a change in the HA:FA ratio. The values of nitrification test were significantly lower because the sources of energy decreased as a result of reduction in the content of readily decomposable organic matters; decreases were also recorded in the average values of C_{BR} and C_{MB}, and in Hendrix's index of biological activity of soil H_{BAS}.

These results documenting the loss of decomposable organic matters in soils if the farming intensity was lower, were fully confirmed by the results of biochemical oxygen demand of soil suspensions expressed by their values BOD_5 and BOD_t and the rate constant k of biochemical oxygen demand as the first order reaction (Table 4). A large difference between the values of BOD_5 and BOD_t and low values of k indicate that the equilibrium of the formation and breakdown of readily decomposable organic matters has been disturbed and these matters are not present in the soil. It has negative impacts on further transformations of soil organic matter, mineralization, humification, and on the microbiological activity of soil, sorption and utilization of soil nutrients and total potential productivity of soil. On the contrary, a view that the content of these matters decreases at a higher intensity of land use is accepted generally.

Table 4. Biological oxygen demand over 5 days (BOD_5), total biological oxygen demand BOD_t and rate constant of BOD as a reaction of the first order

	2001				1986		
Sample	BOD_5 (mg O_2/1000 g)	BOD_t (mg O_2/1000 g)	k_1/24 hours	Sample	BOD_5 (mg O_2/1000 g)	BOD_t (mg O_2/1000 g)	k_1/24 hours
104	191	285	0.08	104	255	310	0.23
106	175	210	0.12	106	210	255	0.18
107	112	204	0.10	107	248	288	0.29
108	124	232	0.06	108	262	314	0.22
109	106	178	0.14	109	154	192	0.20
Average	142	222	0.10	Average	226	272	0.22
	64% BOD_t				83.1% BOD_t		

Among other causes, a slight increase in soil pH can result from a substantial decrease in nitrification, which is the source of H^+-ions (Pitter 1981):

$2\,NH_3 + 4\,O_2 \longrightarrow 2\,NO_3^- + 2\,H^+ + 2\,H_2O$

The watershed waters have a high concentration of HCO_3^-, low concentration of CO_2 because the processes of elution from the soil are delayed beyond the past and present mineralization of labile organic matters in the soil. Chemical oxygen demand COD need not result in the production of biologically decomposable matters but only of oxidizable organic matters. They can be e.g. low-molecular organic matters that are susceptible or little susceptible to biological oxidation. For instance, they could be low-molecular humus acids. This proposition is confirmed by the higher values of COD_{Mn} in surface waters at low values of BOD_5, BOD_t and k in soil suspensions of watershed soils; it should be researched in future.

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REFERENCES

ČSN 83 0530 (1980): Chemický a fyzikální rozbor povrchové vody. Praha, VÚNM.

ČSN 83 0532 (1979): Stanovení saprobního indexu. Praha, VÚNM.

ČSN 83 0550 (1979): Fyzikálně chemický rozbor kalů. Praha, VÚNM.

Eckschlager K. (1971): Chyby chemických rozborů. Praha, SNTL.

Gergel J., Varecha L., Váchal J. (1989): Odnos živin z malých zemědělských povodí jako podklad pro zúrodňování zemědělských půd. Věd. Práce VÚZZP, Praha, *6*: 43–55.

Hendrix P.F., Beare M.H., Cheng W., Parmelee R.W., Coleman D.C., Crossley D.A. (1989): Microbes, microfauna and movements of N-15 among litter, soil and plant pools in conventional and no-tillage agroecosystems. Intercol. Bull., *15*: 59–63.

Kolář L., Gergel J., Ledvina R., Kužel S., Šindelářová M. (2000a): Agrochemická charakteristika půd horských a podhorských oblastí jihovýchodní Šumavy. Rostl. Výr., *46*: 533–542.

Kolář L., Gergel J., Ledvina R., Kužel S., Šindelářová M. (2000b): Železo, hliník a mikrobiální aktivita půd horských a podhorských oblastí jihovýchodní Šumavy. Rostl. Výr., *46*: 543–548.

Kubát J., Voplakal K. (1994): Metody hodnocení množství a kvality půdní organické hmoty. VÚRV, Praha-Ruzyně.

Pitter P. (1981): Hydrochemie. Praha, SNTL.

Sládeček V. et al. (1980): Biologický rozbor povrchové vody. Komentář k ČSN 83 0532 – část 6. Stanovení saprobního indexu. VÚNM, Praha.

Tuček F., Chudoba J., Koníček Z. (1977): Vybrané procesy a výpočty z technologie vody. Praha, SNTL.

Vaněk V., Němeček R., Najmanová J., Mrkvička J. (1997): Vliv způsobu hospodaření, hnojení a úpravy vzorků zemin na obsah rozpustného uhlíku. In: Sbor. Konf. Úloha organických hnojiv v současném zemědělství, Praha, ČZU: 75–80.

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ABSTRAKT

Vliv omezení intenzity zemědělské výroby v Pošumaví na změny organických látek v půdách a kvality povrchových vod

V podhůří Šumavy v devíti povodích potoků v území o ploše 78,5 km^2 byly v letech 1986–1987 a znovu v roce 2001 analyzovány vzorky půd a povrchových vod. Snížení intenzity hnojení a vápnění a další změny v čs. zemědělství způsobily, že poklesl obsah uhlíku C_w a C_{hws} v půdě rozpustného ve studené vodě i v horké vodě, v půdních extraktech poklesl obsah biologicky odbouratelných látek, vyjádřených jako BSK_5 a BSK_c vodných výluhů půdy. Z hodnot rychlostních konstant k kinetiky BSK půdních suspenzí je zřejmé, že půdy Pošumaví mají nejcennější rychle odbouratelné organické látky prakticky zmineralizovány na HCO_3^-, které jsou postupně z půd eluovány a ve zvýšeném množství jsou obsaženy v povrchových vodách. Naopak se ukázalo, že odnos N-NO_3^- poklesl na 66,3 % hodnoty v roce 1986, N-NH_4^+ dokonce na 7,1 %, zvýšila se hodnota poměru C : N a poměru N : P nižší elucí P vzhledem k rovněž méně eluovanému N. Zvýšila se hodnota $CHSK_{Mn}$, vyjadřující poměr lehce odbouratelných látek. Velmi významně poklesla vodivost, tedy obsah rozpuštěných solí ve vodách. Tyto výsledky varují před optimistickou interpretací analýz povrchových vod, které zdánlivě dokazují příznivý vliv celkového omezení intenzity zemědělství v krajině. Výsledky pokusů v Pošumaví dokazují, že pro půdní úrodnost nejcennější složky půdy, odbouratelné organické látky, byly z větší části již odbourány, a proto jejich obsah v půdách klesl. Pro rovnovážnou bilanci těchto cenných látek přirozené zdroje (kořeny, kořenové exsudáty, rostlinné zbytky) při nižší intenzitě zemědělské výroby zřejmě nestačí.

Klíčová slova: organické látky; vztah půdy a povrchových vod; interpretace analýz; změny intenzity zemědělství; povodí

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