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THE EFFECT OF ADDITION OF DIFFERENT AMELIORATIVE COMPOUNDS INTO SEWAGE SLUDGE ON ZINC SORPTION IN SOILS

VLIV PŘÍDAVKU RŮZNÝCH MELIORANTŮ DO ČISTÍRENSKÝCH KALŮ NA SORPCI ZINKU V PŮDÁCH

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ABSTRACT: The investigation of Zn mobility derived from sludge treated by different materials or composted with peat and straw, conditioned under different air environment and subsequently applied into soils was a main objective. Sewage sludge from three waste water factories has been preincubated with addition of lime (18%, w/w), bentonite (30%, w/w) and with peat and straw (50-35-15%) as compost I and (50-5-45%) as compost II for eight months under aerobic and anaerobic environment. Preincubated treatments were mixed with three soils (Fluvisols, Luvisols, and Chernozems) with the portion of 30 g of soil and 1.665 g of preincubated sludge and incubated again for eight months. Amount of available Zn was determined by two extractants (NH_4NO_3, and EDTA) five times during incubation. Results showed extremely low Zn availability from limed treatments compare to zero treatment under both environments determined by NH_4NO_3, but only limited effect when EDTA was used. Bentonite showed almost negligible effect on fluctuation of Zn mobility extracted by both agents. Both composted treatments had a negative influence on Zn mobility and increased it during the whole period of incubation. Treatments preincubated under anaerobic conditions released less Zn than under aerobic ones. Among all factors studied the management of sludge and soil pH showed prevailed effect on Zn availability, higher than a change of sorption capacity or organic matter content.

Keywords: sewage sludge; soil; zinc; lime; bentonite; composts; pH

ABSTRAKT: V inkubačních pokusech byly sledovány změny v sorpci Zn v půdě po aplikaci různě ošetřených čistírenských kalů. V pokusech byly použity tři různé čistírenské kaly, které byly předem inkubovány po dobu osmi měsíců při teplotě 20 °C. Testovány byly kaly neošetřené a kaly s přídavkem bentonitu (30 % z množství sušiny kalu), kaly vyvápněné (18 % $CaCO_3$ z množství sušiny kalu) a kaly kompostované (různý poměr kal : rašelina : sláma) za aerobních a anaerobních podmínek. Na podíl vodorozpustné a výměnné frakce v kalech měly vliv podmínky aerace i přídavek jednotlivých meliorantů. V další fázi experimentů byly s takto ošetřenými kaly založeny nové inkubační pokusy se třemi různými zeminami (černozem, hnědozem a fluvizem). Dávka čerstvého kalu činila 1,665 g sušiny na 30 g jemnozemě. Tyto pokusy trvaly osm měsíců a v pěti termínech bylo sledováno extrahovatelné množství Zn roztokem 1 $mol.l^{-1}$ NH_4NO_3 a 0,025 $mol.l^{-1}$ NH_4EDTA. U variant s kaly preinkubovanými za anaerobních podmínek bylo stanoveno menší množství extrahovatelného Zn. Vápněním se snížila mobilita Zn. Naopak, kompostováním se zvýšil podíl Zn uvolněného roztokem NH_4NO_3 i EDTA. Příčinou tohoto jevu bylo především snížení hodnoty pH samotných kompostů a dále zeminy + kompostů. U variant s bentonitem se zvýšil podíl extrahovatelného Zn roztokem EDTA.

Klíčová slova: čistírenské kaly; půda; zinek; vápnění; bentonit; komposty; pH

INTRODUCTION

The amount of sewage sludge annually applied on agricultural land has been increased for last eight years in Czech Republic. Trend of sewage sludge use well corresponds with other European countries. The application of sewage sludge can bring a positive effect to farmers and supplement soil by organic matter and a wide range of nutrients, but there is a potential hazard of soil pollution by toxic organic compounds and potentially risk elements. Prior to sludge application there is necessary to compare all advantages and disadvantages of its application on agricultural land. There is not just effort to decrease the content of pollutants in sludge but also to minimize mobility of metals present in sludge and subsequently their uptake by plants. Different possibilities are tested for sludge alone and for soils treated by sewage sludge, too. Lime application is the most often used treatment of sewage sludge stabilization (Aichberger, Tauber, 1996) as well as composting (Aldag et al., 1996). A lot of effort was spent to manage suitable soil properties by lime application (Whatmuff, 1999) and by addition of different compounds of high sorption capacity as bentonites (Sims, Boswell, 1978; Tlustoš et al., 1995).

The main objective of our work was focused on investigation of Zn mobility derived from sludge treated by lime, bentonite or composted with peat and straw,

I. Main properties of tested soils

Soil	C_{ox} (%)	pH/KCl	KVK (mval.kg^{-1})	Zn_{tot} (mg.kg^{-1})	Zn_{HNO_3} (mg.kg^{-1})	Zn_{EDTA} (mg.kg^{-1})	$Zn_{NH_4NO_3}$ (mg.kg^{-1})
Chernozems	2.29	7.2	180	116.0 ± 2.0	18.0	3.0	< 0.01
Luvisols	1.54	7.0	145	70.4 ± 1.9	18.6	5.0	< 0.01
Fluvisols	0.96	5.6	75	120.0 ± 10.0	55.3	3.8	1.50

conditioned under different air environment and subsequently applied into soils.

MATERIAL AND METHODS

Three soils and sludge from three different wastewater factories were tested in the incubation experiment. Chernozems (location Suchdol), Luvisols (location Červený Újezd), and Fluvisols (location Přerov) were tested. Main parameters of soils used in the experiment are described in Tab. I.

Treated and untreated sludge used in this experiment has been preincubated for eight months at temperature 20 °C. Five treatments were set up of each sludge, including untreated sludge, were preincubated. Lime was added in the amount of 18% from total dry matter content of sludge, bentonite in the amount of 30%, and two different composts based on the mixture of sludge, peat and straw were made. Compost I contained 50% of sludge + 35% of peat + 15% of straw and compost II contained 50% of sludge + 5% of peat + 45% of straw expressed on dry mass of all components. Total contents of Zn in sludge and in all materials used for sludge amelioration are expressed in Tab. II. Preincubation was done under aerobic (conditioned every second week with air, moisturized and left free in the pot) and anaerobic (filled into pot tightly, press it covered by plastic and seal it) conditions with three replications of each treatment.

Incubation experiments with the mixture of soil and sludge treatments were started after eight months of preincubation. Fresh preincubated sludge containing mixture in the weight equal to 1.665 g dry matter was inserted into 250 ml plastic bottle. Water was added into bottles with sludge in the level of 50% of maximum water holding capacity of individual soil to get maximum homogeneity of incubated mixture of soil plus sludge, then has been shaken for 30 minutes and left for one hour. After this 30 g of soil with particles smaller than 2 mm was added into the bottles sealed with the tops and incubated for 240 days in 20 °C. Bottles were not shaken neither conditioned during the incubation. Content of Zn was determined five fold over the incubation period. First sampling was done at the beginning of experiment (3 hours), and then after 14, 30, 60 and 240 days of incubation. Zn was released by two extractants of different availability using following procedure (Tlustoš, 1999):

- 1 mol.l^{-1} NH_4NO_3 solution was mixed with the solid phase in the ratio 1 : 5 (w/v). Mixture was shaken for 2 hours and then 50 ml of slurry was centrifuged for 10 minutes with 3000 rpm (Hettich Universal 30 RP). Supernatant was stored in fridge (6 °C) until analyses.
- 0.025 mol.l^{-1} NH_4EDTA with pH 4.6 was used in the ratio of 1 : 5 (w/v). Slurry has been shaken for 1.5 hour, centrifuged and stored by the procedure mentioned above.

The whole content of plastic bottles was extracted to elucidate higher variation due to unhomogeneity. Each sample was analysed twice.

Total Zn content in soil was determined by two step decomposition using APION equipment for dry decomposition (Miholová et al., 1993) and mixture of concentrated acids (HF + HNO_3) in the ratio 1 : 2 for decomposition on hot plate (150 °C) of solid part after the first step. Evaporation residue was dissolved by diluted aqua regia and kept in lab until samples were analysed (Mader et al., 1998).

Sewage sludge for determination of total Zn was decomposed by dry ashing procedure and residue dissolved in diluted aqua regia (Mader et al., 1998).

Concentration of Zn was determined by flame atomic absorption spectrometry on VARIAN Spectr-AA-40 equipment in laboratory of Agrochemistry and Plant Nutrion Department of Czech University of Agriculture in Prague.

Quality of analyses was controlled by reference materials RM 7003 Silty Clay Loam in the case of soil with certified content of Zn 81.0 ± 7.6 mg.kg^{-1} and obtained 78.2 ± 4.8 mg.kg^{-1}. Sewage sludge was controlled by RM 12-03-12 Sludge material with certified content of Zn 1310 ± 40 mg.kg^{-1} and obtained 1422 ± 80 mg.kg^{-1}.

Available fractions of Zn in sewage sludge preincubated treatments were also determined by sequential extraction following Száková et al. (1999) procedure.

II. The total content of Zn in sewage sludge and in ameliorative materials at the beginning of preincubation

Used material	mg Zn.kg^{-1} dry matter
Sewage sludge 1	1 524 ± 20
Sewage sludge 2	1 266 ± 42
Sewage sludge 3	471 ± 4
Lime	3.2 ± 0.1
Bentonite	143.2 ± 0.6
Peat	17.2 ± 0.5
Straw	94.3 ± 2

Soil and sludge pH were determined in 0.01 mol.l^{-1} $CaCl_2$ solution with the ratio 1 : 20 (w/v) in the case of sludge and with the 1 : 4 (w/v) in the case of soil plus sludge.

RESULTS AND DISCUSSION

Sewage sludge from three different wastewater factories contained 1524 mg Zn.kg^{-1} in sludge 1, 1266 mg Zn.kg^{-1} in sludge 2 and more than twice lower content 471 mg Zn.kg^{-1} in sludge 3. The results, shown in Tab. III, confirmed the dominant role of Zn in sewage sludge from total Zn pool in preincubated materials. The portion of sludge Zn in treatments with lime represented more than 99%, and with bentonite was from 91.6 (sludge 3) to 96.7% (sludge 1) of total Zn content. Portion of sludge Zn was lower at treatments compost I and compost II (84.6 to 97.4%). Low Zn content in peat caused low portion of peat Zn (0.1 to 2.3%) in all composts in spite of total content of peat in compost I reached about 35%. Higher content of Zn in straw caused an increase of straw Zn portion (1.9 to 15.1%) in composts. The assumption that highest portion of Zn came from sludge was realized in all treatments. Materials added into the sludge predominantly affected chemical properties of the product.

Treated sludge has been preincubated under aerobic (A) and anaerobic (AN) condition, for eight months. During preincubation, the quality of organic matter was transformed and the content of Zn was increased in dry matter of sludge to which corresponded with results of Fricke et al. (1990). The total Zn content and the portion of it in water soluble and exchangeable fractions including sludge pH is displayed in Tab. IV in individual treatments after preincubation. Value of sludge pH was significantly affected by preincubation. Aerobic incubation decreased pH values in all treatments due to higher decay of organic matter, higher CO_2 production, volatilization of NH_3 and faster nitrification. Lime application led to increase of pH and the differences among treated and untreated sludge is higher in aerobic environment than in anaerobic one. Addition of bentonite did not cause almost any changes in pH. The highest drop in pH was found at both compost treatments and was caused by addition of peat. The lowest pH (3.05) was determined in compost I treatment when sludge 3 was incubated.

Different processes occurring during incubation affected Zn content in treatments after preincubation. Higher variation of determined values was caused by heterogeneity of sludge used. Highest Zn contents were found in untreated sludge and the lowest in compost I treatments (Tab. IV). Portion of water soluble and exchangeable fraction of Zn determined by 0.11 mol.l^{-1} CH_3COOH extraction (Tlustoš, 1999) is also displayed in this table. The mobility of Zn was prevailingly decreased by application of lime. Highest portion of water soluble Zn was 1.1% and the portion of exchangeable Zn was 5.6 to 7.1% under aerobic and 1.7% under anaerobic environment at lime treatments. Bentonite application has not substantially changed availability of Zn over preincubation and process of composting led to mobilization of sludge Zn under aerobic conditions above all. Very high level of water soluble Zn was found for sludge 3 in both compost I (36.3%) and compost II (35.2%) treatments. Also both composts based on sludge 2 derived high portion of water soluble Zn (18.6 and 18.3%). Investigated parameters introduced sludge 1 as the most stable one and sludge 3 as at least stabilized.

Incubation experiments were set up on three soils (Tab. I) differed in soil properties, organic matter content, sorption capacity and soil acidity. Total Zn content also fluctuated from 70.4 mg.kg^{-1} in Luvisols to 120.0 mg.kg^{-1} in Fluvisols. The highest portion of mobile Zn was determined on Fluvisols, by EDTA 3.2% and by ammonium nitrate solution 1.3% and the lowest from Chernozems (2.6%, and traces) of total Zn content. Determined values correspond with mean extractability of Zn of Czech soils (Tlustoš, 1999).

The application of high rates of sludge into the soils followed German regulation limits and was fixed as a sum of 100 years maximum rate. The rates of sludge applied into the soil substantially affected the total Zn content in the soils. Untreated sludge 1 delivered 113% of Zn contained in Chernozems, 187% of Luvisols Zn, and 109% of Fluvisols Zn. Sludge 3 with lowest Zn content delivered significantly lower amount of Zn into soils and the portion was 27, 44, and 26% on the same soils. The comparison of mobile Zn forms contained in sludge and in soil amounts used showed even higher proportion of sludge.

Results from 240 days incubation of soil + sludge are summarized in Figs. 1 to 6. Figs. 1, 3, and 5 showed the portion of Zn extracted by NH_4NO_3 solution and Figs. 2, 4, and 6 Zn released by solution of EDTA.

III. The share of Zn content (%) in sewage sludge and in individual ameliorative materials

Treatment	The share of individual components (%)				
	sewage sludge	lime	bentonite	peat	straw
Sewage sludge + lime	99.6	0.4	–	–	–
Sewage sludge + bentonite	95.2	–	4.8	–	–
Sewage sludge + 35% peat + 15% straw	95.5	–	–	1.3	3.2
50% sewage sludge + 5% peat + 45% straw	91.0	–	–	0.2	8.8

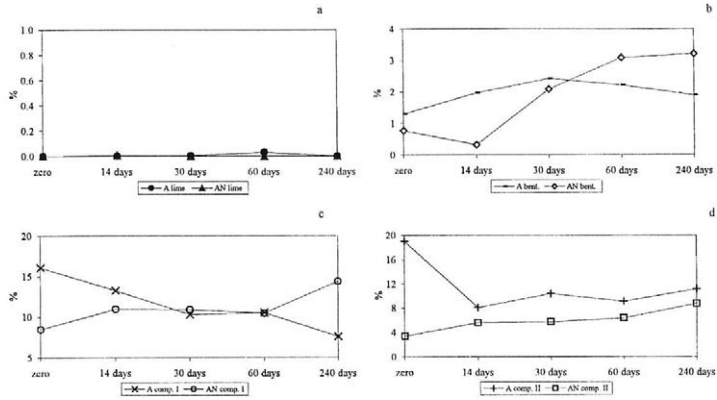
IV. Total Zn content and the portion of water soluble and exchangeable Zn including pH in sewage sludge treatments after eight months of preincubation

Sewage sludge	Treatment	pH/$CaCl_2$	mg $Zn.kg^{-1}$ dry matter	Share of fractions (%)	
				water Zn	exchangeable Zn
1	A1	5.20	2 365	0.9	11.6
	A1 + lime	6.40	1 698	0.1	7.1
	A1 + bentonite	5.20	1 857	0.7	14.5
	A1 + compost I	4.60	1 125	2.9	12.8
	A1 + compost II	4.70	1 318	2.3	2.5
	AN1	6.70	1 642	0.2	5.5
	AN1 + lime	6.80	1 662	0.2	1.7
	AN1 + bentonite	6.70	1 220	0.2	4.1
	AN1 + compost I	4.90	1 065	3.2	19.8
	AN1 + compost II	5.10	1 268	1.1	18.9
2	A2	5.23	1 890	2.7	20.5
	A2 + lime	6.63	1 452	0.1	5.8
	A2 + bentonite	5.40	1 287	1.4	28.3
	A2 + compost I	3.87	1 145	18.6	14.4
	A2 + compost II	3.92	1 296	18.3	12.5
	AN2	7.82	1 399	1.6	0.9
	AN2 + lime	7.32	1 379	0.5	0.2
	AN2 + bentonite	7.81	1 125	0.6	2.0
	AN2 + compost I	4.16	905	12.2	20.1
	AN2 + compost II	5.16	1 182	3.6	26.5
3	A3	5.17	692	0.9	32.3
	A3 + lime	6.07	590	0.1	5.6
	A3 + bentonite	5.65	560	0.2	28.2
	A3 + compost I	3.05	491	36.3	1.2
	A3 + compost II	3.04	553	35.2	10.5
	AN3	7.88	838	0.9	7.2
	AN3 + lime	7.83	705	1.1	0.1
	AN3 + bentonite	7.83	641	1.3	5.7
	AN3 + compost I	6.01	554	0.8	13.1
	AN3 + compost II	6.73	586	1.3	10.2

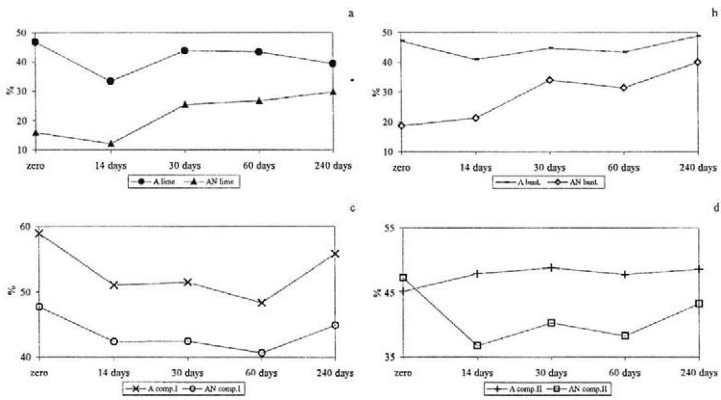
A – aerobic incubation
AN – anaerobic incubation

Suitable use of both extractants for determination of available Zn pool was supported by Zeien, Brümmer (1991), Zeien (1995) and Liebe et al. (1997) results. The portion of Zn released by both extractants at individual treatments was expressed as sludge Zn due to incubation of untreated and treated soils under the same conditions. Balance method: content of $Zn_{sludge} = Zn_{soil + sludge} - Zn_{soil}$ was built on the assumption, that incubation of soil or sludge + soil treatments allow to soil to release the same amount of Zn from both treatments and is not affected by sludge present. Design of displayed figures with four subfigures (a–d) and with only two treatments in each subfigure was made for easier understanding of trends. Each point of figure was constructed as mean value of 18 partial analyses (3 soils x 3 sludge x 2 replications) to eliminate the variation caused by heterogeneity of preincubated material used. Sorption of elements is significantly affected by soil acidity (Tiller et al., 1984; Blume, 1994), therefore initial pH in all treatments was determined after 24 hours of incubation (Tab. V). Results showed that sludge preincubated under lack of air increased pH of soil.

Effect of air availability for treatments during preincubation on the availability of Zn during incubation is shown in Figs. 1 and 2. Higher pH of anaerobically preincubated sludge affected mobility of Zn during incubation. The amount of Zn released by both extractants was lower at anaerobicaly preincubated sludge which corresponded with higher pH at these treatments. Except higher pH, lower Zn availability can be affected by sulphur reduction from S^{VI+} and S^{IV+} oxidation states to S^{II-} to allow development of almost insoluble



1. Available Zn of sewage sludge (%) released by NH_4NO_3 over incubation experiment from soils treated by aerobically (A) and anaerobically (AN) preincubated sewage sludge

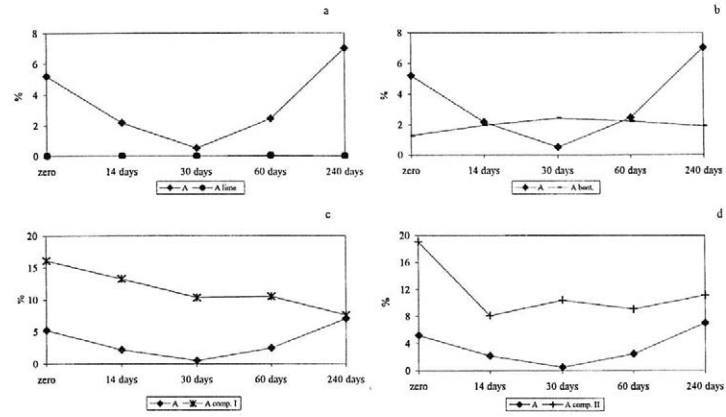


2. Available Zn of sewage sludge (%) released by EDTA over incubation experiment from soils treated by aerobically (A) and anaerobically (AN) preincubated sewage sludge

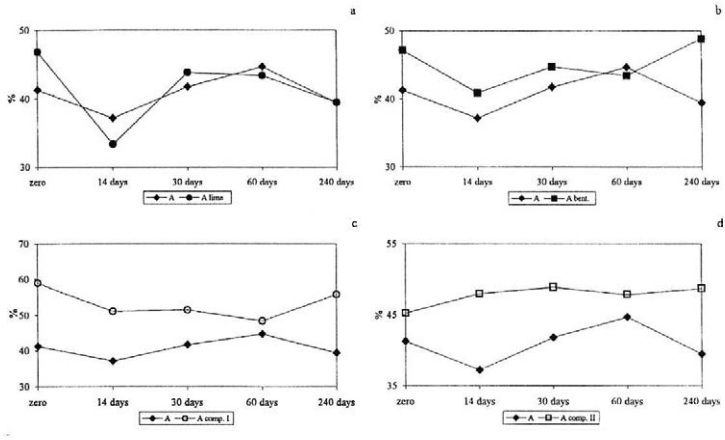
100% – A lime Zn_{tot} = 1276 mg.kg^{-1}
100% – AN lime Zn_{tot} = 1249 mg.kg^{-1}
100% – A comp. I Zn_{tot} = 920 mg.kg^{-1}
100% – AN comp. I Zn_{tot} = 841 mg.kg^{-1}
100% – A bent. Zn_{tot} = 1234 mg.kg^{-1}
100% – AN bent. Zn_{tot} = 995 mg.kg^{-1}
100% – A comp. II Zn_{tot} = 1055 mg.kg^{-1}
100% – AN comp. II Zn_{tot} = 1012 mg.kg^{-1}

Zn compounds no extractable by NH_4NO_3, neither by EDTA. The effect of lower Zn mobility in preincubated sludge survived for the period of incubation. High difference in Zn mobility of soils treated by aerobically and anaerobically conditioned sludge could be also caused by no soil cultivation during 240 days of incubation. Fig. 1a showed very efficient behaviour of lime addition on the drop of Zn mobility over incubation with all soils. NH_4NO_3 extraction did not release almost any Zn. The extraction by EDTA was more effective (Fig. 2a) and differences between both treatments were higher with the similar trend except AN lime treatment, where was found a tendency for higher mobility during incubation. The Zn extraction at the beginning was 15.9% and at the end 29.8%.

The effect of air on Zn mobility during the incubation of sludge treated by bentonite is shown in Fig. 1b. The extraction by NH_4NO_3 showed lower amount of Zn released from anaerobically conditioned sludge only in the period of first 30 days, further incubation showed opposite trend mostly due to sludge 2. The rest of treatments showed similar values of availability. Easy visible differences between both treatments were found in EDTA extracts (Fig. 2b). Soils treated by aerobically incubated sludge (A bent.) released stable amount of sludge Zn during the whole period of incubation (41 to



3. Available Zn of sewage sludge (%) released by NH_4NO_3 over incubation experiment from soils treated by aerobically preincubated sewage sludge with ameliorative materials



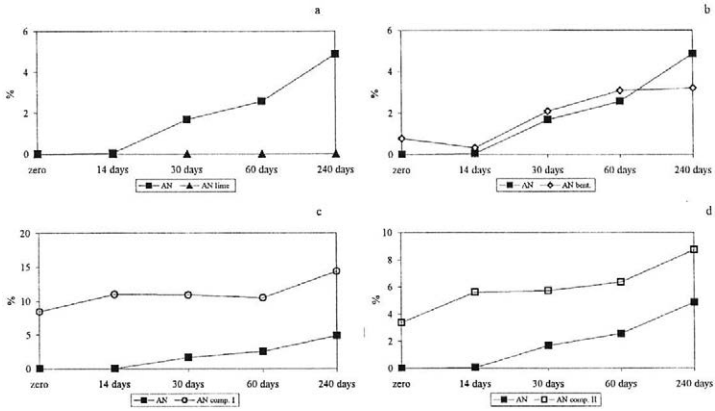
4. Available Zn of sewage sludge (%) released by EDTA over incubation experiment from soils treated by aerobically preincubated sewage sludge with ameliorative materials

100% – A Zn_{tot} = 1649 mg.kg^{-1}
100% – A lime Zn_{tot} = 1276 mg.kg^{-1}
100% – A comp. I Zn_{tot} = 920 mg.kg^{-1}
100% – A bent. Zn_{tot} = 1234 mg.kg^{-1}
100% – A comp. II Zn_{tot} = 1055 mg.kg^{-1}

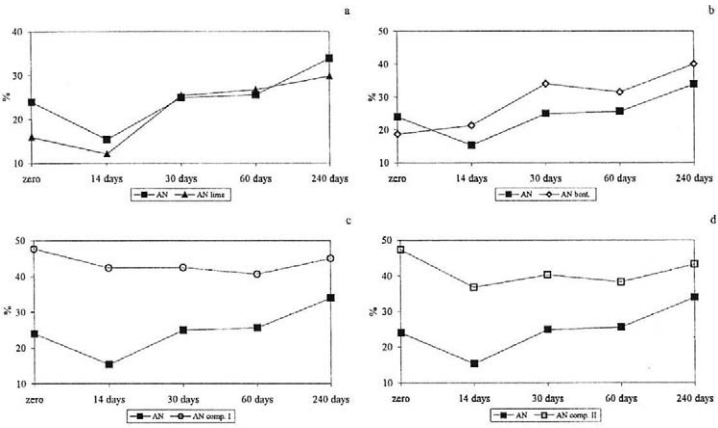
49%). Treatments with anaerobic (AN bent.) sludge showed regular increase of Zn mobility from 18.8 to 40%, probably caused by faster transformation of organic matter in anaerobically preincubated sludge.

Both compost treatments showed the same trend as other treated sludge. Under anaerobic environment Zn was less mobile over incubation with the exception of EDTA extract in AN comp. II treatment at the beginning of experiment (Fig. 2d). The results of EDTA were not in good relation with NH_4NO_3 extraction of the same treatment, but Zn extractability was few times lower there. Low Zn mobility was mostly caused by sludge 1. Anaerobically conditioned comp. II treatment contained 21% of Zn in easily mobile forms after preincubation and aerobically treated comp. I only 4.8% after preincubation.

Efficiency of individual treatments on Zn mobility compared to untreated sludge is described in Figs. 3 to 6. Rate of lime used in the experiment was high and $CaCO_3$ was used. The application of $CaCO_3$ increased the rate of material applied and allowed slow release changes in soils with low attack of organic matter. Application of carbonate is in good agreement with common agricultural practices. High rate of sludge applied caused also an application of high rate of $CaCO_3$ into the soil (about 15.7 t $CaCO_3$ per 1 ha) and an increase



5. Available Zn of sewage sludge (%) released by NH_4NO_3 over incubation experiment from soils treated by anaerobically preincubated sewage sludge with ameliorative materials



6. Available Zn of sewage sludge (%) released by EDTA over incubation experiment from soils treated by anaerobically preincubated sewage sludge with ameliorative materials

100% – AN Zn_{tot} = 1293 mg.kg^{-1}
100% – AN lime Zn_{tot} = 1249 mg.kg^{-1}
100% – AN bent. Zn_{tot} = 995 mg.kg^{-1}
100% – AN comp. I Zn_{tot} = 841 mg.kg^{-1}
100% – AN comp. II Zn_{tot} = 1012 mg.kg^{-1}

of soil pH (Tab. V). The highest increase was found on Fluvisols corresponding with low sorption capacity of that soil. Treatment with the addition of aerobically unlimed preincubated sludge showed pH 5.1 and with limed sludge showed 6.3. Treatments with anaerobically preincubated sludge showed less variation and lime caused an increase of pH from 6.4 to 6.8. Other two soils introduced less changes in pH corresponding with sorption capacity of soil and content of carbonates in Chernozems and Luvisols.

Lime application decreased the mobility of Zn extracted by NH_4NO_3 and almost no Zn was released under aerobic and anaerobic environment (Figs. 3a, 5a), that corresponded well with changes of pH in preincubated sludge and also in incubated soils. EDTA was able to release Zn from stronger bounds and the immobilization effect of lime of aerobically incubated sludge was not confirmed (Fig. 4a), but a preincubation under anaerobic condition showed lower Zn availability in the first part of experiment (Fig. 6a).

Application of bentonite into sludge did not make much difference in Zn availability compare to zero treatments. An application of sludge with bentonite into soil showed similar trend especially for A bent. treatments (Figs. 3b, 4b). The change of sorption was less effective than pH increase. Treatments (A bent.) introduced lower pH values in all soils than zero treatments (A) (Tab. V). Anaerobically treated sludge (AN bent.)

V. The level of pH in soils treated by sewage sludge after 24 hours of incubation (average of three sewage sludge)

Soil	Treatment	Aerobic incubation	Anaerobic incubation
Chernozems	sewage sludge	7.18	7.53
	sewage sludge + lime	7.44	7.66
	sewage sludge + bentonite	7.02	7.53
	compost I	6.40	6.65
	compost II	6.41	6.87
Luvisols	sewage sludge	6.41	7.10
	sewage sludge + lime	6.73	7.21
	sewage sludge + bentonite	6.22	7.13
	compost I	5.15	5.66
	compost II	5.30	6.09
Fluvisols	sewage sludge	5.13	6.41
	sewage sludge + lime	6.29	6.75
	sewage sludge + bentonite	5.15	6.67
	compost I	4.08	4.64
	compost II	4.15	5.22

showed almost the same values of pH as zero treatment with a good relation to Zn extractability by NH_4NO_3 (Fig. 5b). Portion of Zn released by EDTA is described in Figs. 4b and 6b. Both treatments showed higher extractability of Zn from treated sludge by bentonite than from untreated one. Our findings well corresponded with assumption that Zn should be bound mostly by nonspecific adsorption on bentonite surface and easily extracted by EDTA (Beckett, 1989).

Composting of sewage sludge with peat and straw clearly led to higher mobility of Zn mostly caused by higher acidity of compost alone and a mixture of compost + soil. Acidification mostly occurred in aerobic environment and was highest on Fluvisols due to its low sorption capacity. Zn mobility was higher in compost I than compost II treatments, which corresponded with changes of pH in both composts and in soils. Higher Zn mobility caused by low pH values was not compensated by high sorption capacity of peat used neither the lowest amount of Zn applied by this treatment into the soil. Low affinity of Zn for peat also found Alloway (1990) and Ross (1994). Both composts also showed the lowest difference between anaerobically and aerobically preincubated treatments caused by lowest portion of sludge among all treatments and higher aeration of anaerobic pots by addition of well structured components (peat and straw). All diverse factors caused much higher Zn availability in both compost treatments extracted by NH_4NO_3 (5 to 19%) (Figs. 3c, d, and 5c, d) than was determined in the rest of treatments (0 to 2%). Prevailing processes of composting supported transformation of Zn into very mobile fractions in spite of Zn immobilization. Always higher extraction of Zn from compost treatments than from control ones was also found by EDTA solution (Figs. 4c, d and 6c, d). Extremely high Zn mobility in composts confirmed transformation of element from nonmobile fractions into mobile ones and Zn extractability from exchangeable and mild organic bounds (Ure et al., 1993). Beckett (1989) also mentioned ability of EDTA to release part of Zn bound on carbonates and oxides.

Our results showed that more detailed studies of individual processes occurring in sewage sludge and after application of sewage sludge into soils are needed. There is necessary to understand Zn transformation among its fractions in sludge and in the mixture of sludge + soil. Analyses showed the addition of ameliorant caused dilution of metal contents in sewage sludge, but it did not lead to lower mobility of Zn. Results also showed suitability of lime application into sewage sludge and necessity to maintain pH of composted sludge with other organic compounds. Lime application into sludge was substantially more effective than addition of bentonite from the point of Zn mobility and well corresponded with investigation of Cd mobility (Balík et al., 1999; Balík et al., 2000). Results also showed necessity of investigation of Zn binding during a storage of sludge under different air environment.

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SOME SWARD CHARACTERISTICS OF SEMINATURAL AND OVERSEEDED PASTURE UNDER CONTINUAL GRAZING OF HEIFERS

NĚKTERÉ CHARAKTERISTIKY POLOPŘIROZENÉHO A PŘISETÉHO PASTEVNÍHO POROSTU KONTINUÁLNĚ SPÁSANÉHO JALOVICEMI

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ABSTRACT: The effect of oversowing of white clover and ryegrass under continual grazing of heifers on some sward characteristics was studied in an experimental pasture in the Jizerské hory Mountains (lat. 51° 20' N, long. 15° 02' W) from 1993 to 1997. There were two treatments reseeded pasture (PR) and pasture without reseeding (P0). The number of grass tillers, clover stolon growing points (sgp) and forbs were measured three to four times during the grazing season at each treatment. The oversowing of white clover and ryegrass did not increase either number of grass tillers nor sgp of white clover. The number of white clover sgp even more raised on the pasture without reseeding (P0) than with reseeding (PR). There was a general trend for sgp to gradually increase during the grazing season. On the contrary, the number of grass tillers was highest at the beginning and end of the grazing season. No differences between pastures with (PR) and without (P0) reseeding were found in the number of grass tillers and forbs. The number of forbs peaked in the first and last grazing cycle. The seasonal fluctuation of the present species was the main effect on the number of clover sgp, grass tillers and forbs. The oversowing of white clover is not necessary, when at least some white clover plants are present in pasture sward or in adjacent pastures, and the high grazing pressure allows to suppress grass growing and supports growing of clover. This applies for more heterogeneity (about 20 species) and an open sward that was on studied experimental pasture.

Keywords: grassland; oversowing; continual grazing; sward characteristic

ABSTRAKT: Byly sledovány některé charakteristiky travního porostu na přiseté pastvině (PR) a pastvině bez přísevu (P0) při kontinuálním systému pastvy jalovic. Experiment proběhl v letech 1993 až 1997 na pokusné pastvině v Jizerských horách (ϕ = 51° 20'; λ = 15° 02'). Expozice pozemku je jihovýchodní, nadmořská výška 420 m, svažitost 9°. Povětrnostní faktory jsou charakterizovány ročním úhrnem srážek 803 mm a průměrnou roční teplotou 7,2 °C. Nejvyšší zastoupení v porostu měly druhy: *Agrostis capillaris*, *Lolium perenne*, *Trifolium repens* a *Taraxacum officinale*. Pokusné plochy tvořily 2 ha mezofilního travního porostu, rozděleného na dvě části, každá o rozloze 1 ha. Na polovinu pastviny (PR) byl v roce 1990 přiset bezorebným secím strojem SE 2024 (výrobce SOR Libchavy) jetel plazivý (*Trifolium repens*), odrůda Pastevec s výsevkem 6 kg.ha^{-1} ve směsi s jílkem vytrvalým (*Lolium perenne*), odrůda Bača s výsevkem 5 kg.ha^{-1}. Druhá část pastviny (P0) byla bez přísevu. Výška pastevního porostu byla udržována v průběhu celého pokusu 5 až 7,5 cm. Počet travních odnoží, růstové body jetele plazivého, resp. počet ostatních dvouděložných bylin byly sledovány na randomizovaných obdélnících 0,05 m x 0,2 m v deseti opakováních v každé variantě, tři- až čtyřikrát v průběhu pastevní sezony. Přísev jetele plazivého a jílku vytrvalého nezvýšil počet růstových bodů jetele plazivého ani počet travních odnoží (tab. III). Počet růstových bodů jetele plazivého byl naopak vyšší u porostu nepřisévaného, kde se podíl jetele plazivého zvýšil z méně než 1 % na 30 % (obr. 2). Počet růstových bodů jetele plazivého se u obou variant v průběhu pastevní sezony postupně zvyšoval (obr. 1). Počet travních odnoží byl nejvyšší na začátku a na konci pastevního období. Nebyly zaznamenány žádné rozdíly mezi variantami v počtu travních odnoží ani v počtu bylin. Počet bylin měl podobně jako počet travních odnoží vrchol na začátku a na konci pastevního období. Sezonní fluktuace zastoupených druhů měla hlavní vliv na sledované charakteristiky travního porostu. Přísev jetele plazivého do pastevního porostu není nutný, jestliže je v porostu i v malém množství zastoupen, resp. pokud se vyskytuje v přilehlých porostech. Pro jeho optimální zastoupení v pastevním porostu je důležitý odpovídající pastevní tlak, který potlačí růst ostatních složek porostu. Platí to pouze pro pastevní porost s vyšším podílem trav, které vytvářejí méně hustý drn.

Klíčová slova: travní porosty; přísev; kontinuální pastva; charakteristiky porostu

INTRODUCTION

The oversowing of leguminous and grasses helps to introduce leguminous plants and grasses into meadows and pastures. Main cause for oversowing is improving yield and nutritive composition of forage. White clover is an important plant for pasture sward, because it contributes to high quality forage and by means of its symbiotic relationship with rhizobia bacteria it also fixes atmospheric N for its own growth and for that of the grass.

For oversowing of white clover generally seeding rate is around 5 kg.ha^{-1}. In the Czech Republic for pasture improving Kohoutek et al. (1998) recommended oversowing of white clover in rate 6 to 7 kg.ha^{-1}. For further maintaining the right rate of clover in sward is important grazing management and pressure. Frequent grazing mostly supports spreading of white clover into pure grass sward with lower density. Gibb et al. (1989) found that sward with markedly different levels of white clover at the start had after four years of experiment with continuously stocked cattle similar clover contents. Similarly Laidlaw et al. (1995) noted that the clover content under continuous cattle grazing was not greatly changed in the long term experiment during the grazing seasons. Rais, Královec (1989) found the same rate of white clover in the yield on pastures with and without oversowing under the same grazing pressure.

The experiment described here was carried out in Liberec (Grassland Research Station) to study the change of number white clover sgp, grass tiller and forb on seminatural and overseeded pasture under continual grazing of heifers over five years.

MATERIAL AND METHODS

Experimental site and management

The experiment was carried out from 1993 to 1997 in an experimental pasture in the Jizerské hory Mountains (lat. 51° 20' N, long. 15° 02' W). The altitude of the experimental pasture is 420 m. The average annual precipitation for the area is 803 mm. The mean annual temperature is 7.2 °C. The dominant species are common bent (*Agrostis capillaris* L.), ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and dandelion (*Taraxacum officinale* Web.). No fertilizers have been applied since 1992.

There were two treatments: overseeded pasture (PR) and pasture without reseeding (P0), both of them on 1.0 ha. Each area was grazed by four to five young Czech Pied heifers in 1993, by six young Friesian x Czech Pied heifers in 1994 to 1996 and by four to five young crossbreed Czech Pied x Charolle or Friesian heifers in 1997. The sward on both treatments was maintained at a height of 5 to 7.5 cm by varying the grazing area available for treatment and by reducing the number of heifers in late summer. The grazing season lasted from the beginning of May to the end of September or the middle of October.

The pasture sward without legumes was overdrilled by white clover (*Trifolium repens* L. cv. Pastevec) at seeding rate of 6 kg.ha^{-1} in mixture with perennial ryegrass (*Lolium perenne* L. cv. Bača) at seeding rate of 5 kg.ha^{-1}, on 15th March 1990. Reseeding was made by slot seeding drill SE 2-024 (manufactured by SOR Libchavy, Ltd.). Before this experiment PR pasture was rotationally grazed by heifers and P0 pasture was once cut in June and after that moderately grazed in September. At the beginning of this experiment P0 pasture had cover of indigenous white clover less than 1%.

Sward measurements

The sampling sites during the whole experiment were the first part of the grazing area (0.166 ha) at both swards. The number of grass tillers, white clover stolon growing points (sgp) and forbs were calculated from the ten randomized quadrats (20 x 5 cm) three to four times during the grazing season in each treatment. In these quadrats the white clover was cut to obtain all surface and buried stolons. Samples of stolons were stored frozen, then measured for the number of sgp. In spring and late summer in each sampling site we determined the percentage of the ground surface covered by all plant species with a 10 x 10 m area. Sward height was measured using the first contact method twice weekly on grazed plot (100 per plot) on both treatments.

Statistical analysis

Clover sgp, grass tiller and forbs measurements were analyzed by ANOVA-like generalized linear model (GLM) using program S plus 4.5.

RESULTS AND DISCUSSION

Weather conditions

Monthly records of rainfall and mean temperatures collected at the meteorological station in Liberec (5 km from experimental sites) are shown in Tab. I, and demonstrate a period of several weeks in each year, during July (especially 1994, 1995), when rainfall was much lower than the long term average. The sward height for each treatment was similar (Tab. II).

Clover stolon growing points

At the beginning of the experiment less than 1% of white clover plants were not found in P0 treatment, in PR the number sgp was about 6200.m^{-2} (Fig. 1). During the grazing season 1993, the number of sgp for treatment PR increased until June 1994. At the start of grazing season 1994 first plants of white clover were found in P0, that spread probably from adjacent pasture

I. Monthly rainfall (mm), mean daily air temperature (°C) and their 30-year average total or mean

Month	Rainfall					Air temperature				
	1993	1994	1995	1996	1997	1993	1994	1995	1996	1997
1.	36.5	98.4	103.7	6.3	12.6	0.2	1.7	–2.1	–4.9	–4.6
2.	57	26	67.3	6.8	58.5	–1.9	–1.5	2.9	–4.9	1.5
3.	50	102.1	68	53.3	40	1.4	4.7	1.9	–1.6	3.4
4.	39	57.4	56.1	29.6	96.9	9.2	6.8	7.4	7.2	3.8
5.	44.6	71	104.8	162.8	93	14.6	11.7	11.6	10.9	12.1
6.	63.3	63.1	131.1	68.9	114.8	14.5	14.5	13.7	14.9	15.3
7.	223.5	22.1	40.8	159.6	224.4	15.3	21	19.6	14.8	15.8
8.	96.9	155.4	153.7	102	55.9	15.5	17.1	17	16.3	18
9.	104.9	70.9	114.3	97.9	23.4	11.7	13.2	11.8	9.2	12.1
10.	45.1	54.2	12.5	56.4	76.5	7.6	6.4	10.7	9.2	5.7
11.	76.6	66	77.6	44.4	39.8	–0.1	5.2	0.2	4.5	3.1
12.	124.9	94.6	54.7	38.9	98.8	1.6	1.4	–2.9	–5.4	0.7
Total or mean	962	881	985	827	935	7.5	8.5	7.7	5.9	7.2
30-year average total or mean			803					7.15		

II. Mean sward height

	1993	1994	1995	1996	1997
PR mean sward height (cm)	6.90	6.63	6.03	5.83	6.69
s.e.m.	0.06	0.07	0.06	0.05	0.05
P0 mean sward height (cm)	6.34	6.57	5.88	6.52	6.00
s.e.m.	0.05	0.06	0.05	0.06	0.05

with white clover. In July and August 1994 the long term water deficiency (Tab. I) decreased sgp on both treatments. This lower number of sgp lasted in PR until May 1995, then the number of sgp started to increase again. While the numbers of sgp in P0 gradually increased until August 1995, after that fell down, however, were mostly higher than in PR sward. From August 1996 the shape of the curve was very similar in both treatments, but number of sgp was higher in P0 treatment.

The lowest number of sgp was at the beginning of the grazing season (848 sgp.m^{-2}) and increased through the grazing seasons, when it peaked in the fourth grazing cycle to 2064 sgp.m^{-2} with significant differences between grazing cycles ($P < 0.001$). Also Gibb, Baker (1989) noted that sgp densities under beef cattle grazing were increased during the later part of the season. The average number of sgp gradually increased during the years of the experiment and was mainly influenced by high number of sgp in P0 treatment.

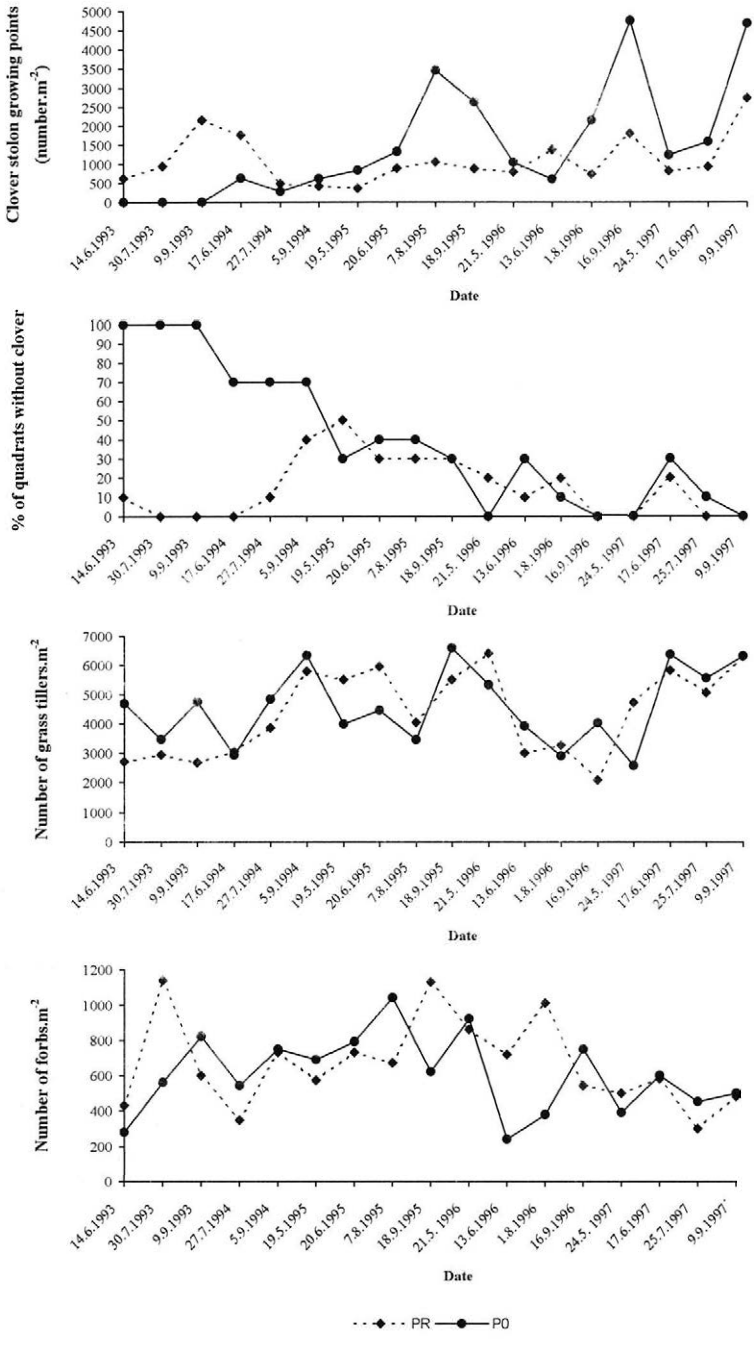
Low density was mainly caused by higher number of measured quadrats without clover in both treatments than lower density of sgp in each quadrats (Fig. 1). Sgp density averaged over all measurements each year and was significantly higher ($P < 0.05$) in the treatment P0 than in the PR treatment (Tab. III). There was also found significant differences among years ($P < 0.001$), what could be caused by seasonal variation of white clover.

Grass tillers

The average number of grass tillers tended to be greatest with P0 with high variation in both treatments sites during the grazing seasons (Fig. 1) without significant differences (Tab. III). With lower summer precipitation in July (1994, 1995), the grass tillers increased at both treatment sites. Contrary to the white clover sgp, the number of grass tillers was highest at the beginning 4752.m^{-2} (grazing cycle 1) and at the end 5029.m^{-2} (grazing cycle 4) of the grazing season. In consecutive grazing cycle they fell to 4286.m^{-2} (grazing cycle 2), 3936.m^{-2} (grazing cycle 3) and tended to be different ($P < 0.05$) (Tab. III). There were high variations among years with significant differences ($P < 0.001$). The higher number of grass tiller was generally found in the year with a higher summer temperature.

Forbs

Fig. 1 presents the mean number of forbs during grazing experiments. The average number of forbs was similar in both treatments without significant statistical differences (Tab. III). Significant differences were found among years ($P < 0.01$). The maximum number of forbs occurred in the first grazing cycles, when many forbs were at their growing peak, and in the last grazing cycle when grass growth rates are much lower (Fig. 1).



1. Population density of white clover, grass and forb on reseeding pasture (PR) and pasture without reseeding (P0) under continual grazing of heifers

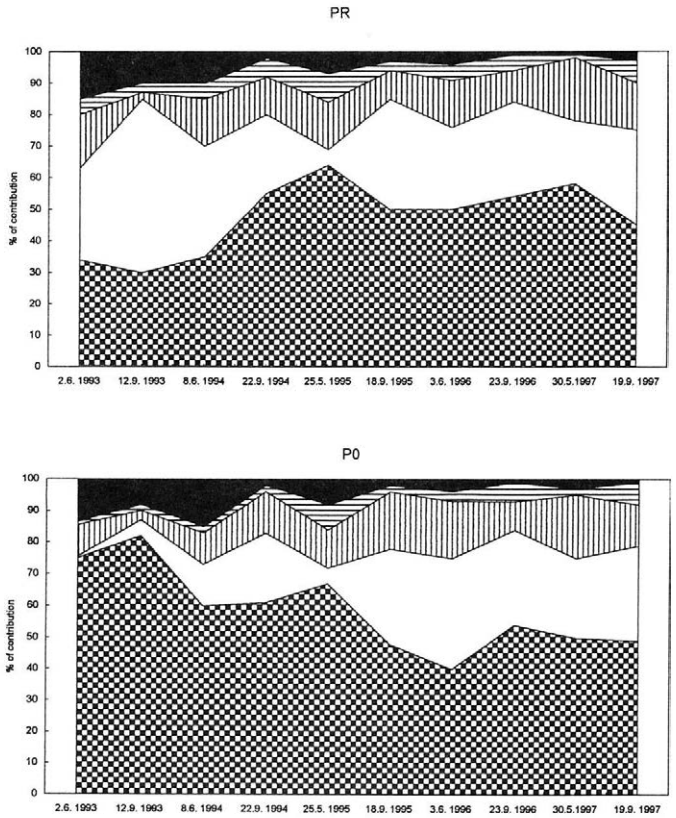
Botanical composition

Changes in species composition through the season are shown in Fig. 2. At the beginning of the experiment the presence of white clover plants in P0 pasture was less than 1%. White clover generally increased as the grazing season progressed in all years at both treatments. Similarly small differences between clover content in overseeded pasture and pasture without seeding was also noted in Bohemian conditions by Rais, Královec (1989). After the long term water deficiency (Tab. I) in July and August 1994 decreased white clover

III. Mean plant density of grass (tillers.m^{-2}), white clover (growing points.m^{-2}) and forbs (plants.m^{-2}) on reseeded (PR) and non reseeded (P0) pasture under continual grazing system

Treatment	Grasses		White clover		Forbs	
	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.
PR	4 367	198	1 134	97	663	44
P0	4 578	212	1 572	192	601	40
Significance	NS		*		NS	
1993	3 535	198	620	134	638	76
1994	4 465	310	694	131	573	59
1995	4 934	362	1 426	297	780	71
1996	3 859	295	1 648	218	681	73
1997	5 335	330	2 030	257	475	40
Significance	***		***		**	
Grazing cycle 1	4 752	367	848	111	657	91
Grazing cycle 2	4 286	269	964	123	546	42
Grazing cycle 3	3 936	215	1 334	226	644	57
Grazing cycle 4	5 029	315	2 064	270	692	57
Significance	*		***		NS	

NS = not significant
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$



2. Botanical composition of the sward on reseeding pasture (PR) and pasture without reseeding (P0) under continual grazing of heifers

- empty places
- other forbs
- *Taraxacum officinale*
- *Trifolium repens*
- grasses

on both treatments in September measurement. The rate of grasses and dandelion (*Taraxacum officinale*) was mostly highest in spring and then declined in September. The proportion of other forbs varied from 1 to 9% over the grazing experiment. In years of summer drought, white clover may be replaced by dandelion and other forbs. However, white clover seems to recover to its average percentage in years with a regular distribution of precipitation..

CONCLUSION

In the present study, the tiller densities and number of clover stolon growing points were considerably lower than results from seaside areas. The causes are more heterogeneity (about 20 species) and an open sward under different soil and weather conditions. The oversowing of white clover and perennial ryegrass did not increase either the number of grass tillers or clover sgp. On the contrary, the pasture without reseeding had at the end of experiment highest number of sgp. The number of clover sgp was gradually increased during the grazing season in both treatments. Maximum number of forbs and grass tillers was in the first and last grazing cycles. The number of clover sgp, grass tillers and forbs were mainly influenced by the seasonal fluctuation of the present species. The oversowing of white clover is not necessary, when at least some white clover plants are presented in pasture sward or in adjacent grasslands and higher grazing pressure allows to suppress grass growing and supports growing of clover. These conclusions apply for heterogeneity and open sward that was in studied experimental pasture sward.

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VLIV ZPRACOVÁNÍ PŮDY K PŘEDPLODINĚ NA VÝNOS ZRNOVÉ KUKUŘICE A OZIMÉ PŠENICE V SUŠŠÍ OBLASTI JIŽNÍ MORAVY

THE EFFECT OF PREVIOUS CROP SOIL CULTIVATION ON THE YIELD OF GRAIN MAIZE AND WINTER WHEAT IN THE DRIER AREA OF SOUTHERN MORAVIA

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ABSTRACT: The work presents the results of minimization in soil cultivation at the seeding sequences: 1. seed maize, 2. seed maize, 3. winter wheat, 4. winter wheat. These seeding sequences have been repeated several times at the experimental site in Hrušovany u Brna and represent a four-year period of 1990 to 1993 incl. The experiment was organized with the method of randomized blocks at four repetitions. Three systems and ways of soil cultivation were established at the experimental sites. Variant I assigns processing tillage at all crops of the four-year seeding plan. Variant II (limited cultivation) only claims tillage for maize at the sequence 1. For maize at the sequence 2 and for the double sequence of winter wheat the soil cultivation is realized with plate tools. Variant III (variant without soil cultivation) claims tillage for seed maize at the sequence 1, soil cultivation with plate tools for seed maize at the sequence 2. For winter wheat at the sequences 3 and 4, no-till seeding with no soil cultivation was processed. The tillage for seed maize was processed to the depth of 0.24 m, for winter wheat 0.20 m, always with plough. At the limited soil cultivation for seed maize (to the depth of 15 cm) and winter wheat (12 cm) plate stubble plough. Fertilization was processed uniformly at particular soil cultivation variants. For the seed maize at the sequence 1, wheat straw and pig slurry (50 $t.ha^{-1}$) were mulched into the soil together with artificial fertilizers (at the conversion to $kg.ha^{-1}$ 140 kg N, 176 kg P_2O_5, 361 kg K_2O). Then follows seed maize at the sequence 2 where maize straw and 220 kg $N.ha^{-1}$ were used as a fertilizer. The winter wheat of the sequence 3 was fertilized with 20 kg $N.ha^{-1}$ on the leaf and at the sequence 4 the amount was 100 kg $N.ha^{-1}$ before seeding. At all soil cultivation variants, the crops were uniformly treated with herbicides according to the valid plant protection methodology. In 1989 and 1993 soil samples were taken from the depth of 0 to 0.1 m, then 0.1 to 0.2 m and 0.2 to 0.3 m for monitoring the effect of the long-time impact of soil cultivation intensity on soil physical characteristics. The basic indicators of soil physical characteristics were assessed according to the comprehensive methodology of complex soil research. The yield of grain and straw was cast by calculation of harvested products from the area of the experimental plots on the area of 1 ha on $t.ha^{-1}$ according to the soil cultivation variants. These data were later evaluated by the method of variance analysis. According to the mean numerical data of 1989 (the time of initial state of monitoring) and 1993 (the end of the experiment), the soil physical characteristics showed a certain tendency of soil settling at the variant 1 (tillage). Much more remarkable changes of soil physical characteristics were monitored in this period at applying the minimization elements. The monitored changes certify a progressive soil concretion during the time. In relation to the demands of the experimental crops there was not monitored soil deterioration to such extent that the changes would negatively influence the growth, development and the final production. As to the evaluation the crops of maize and winter wheat seed, the yield was influenced by three factors: the year, the position at the crop sequence and the soil cultivation variant. The influence of the year during the time of the experiment (1990 to 1993 incl.) showed that for seed maize the years 1991 and 1993 were the most favourable, lower crop was observed in 1990 and the absolutely lowest in 1992. The highest crop of winter wheat influenced by the effect of the year was in 1990 and 1991, then comes the year 1993 and the absolutely lowest crop was in 1992 just like maize. Another factor influencing the crop results of maize and winter wheat was the position of the crop within the framework of the seeding sequence. At the sequence 2 (maize after maize) higher crop was observed. The crop of winter wheat was significantly higher at the sequence 3 (except the year 1992) when it was planted after a double sequence of seed maize. At the sequence 3 (wheat after wheat) the crop was lower in 1990, 1991 and 1993, the reason are generally known demands of wheat on the preceding plant. The third factor of the soil cultivation variants I, II and III had the least influence on the yield of maize and winter wheat. The monitored crops were balanced with minimal differences, statistically inconclusive (except the sequence 1, variant III). The reason can be among others high natural soil fertility which can eliminate crop differences between the monitored soil cultivation variants at the experimental sites as well as relatively high level of nutrition of experimental crops. Similar results were certified even in the case of achieved production of side products of maize and winter wheat straw. The same goes for the case of productivity evaluation of the four-year experimental sequence according to soil cultivation variants in cereal units at the conversion to 1 ha. The applying of minimization elements

at soil cultivation issues from the principle that the traditional tillage soil cultivation on one hand and the limited soil cultivation including seeding into uncultivated soil on the other hand is not self-contradictory in the soil management system of an agriculture company but, on the contrary, complementing each other. This is the only way to use the agrotechnical strengths of both of the systems at the synchronous limitation interference into production and achieving a significant economic gains at plant production.

Keywords: winter wheat; seed maize; seed sequence; soil cultivation; soil physical characteristics; yield

ABSTRAKT: Jsou prezentovány výsledky dlouhodobé minimalizace zpracování půdy v rámci osevního sledu: 1. kukuřice na zrno, 2. kukuřice na zrno, 3. ozimá pšenice, 4. ozimá pšenice, v časovém úseku let 1990 až 1993. Sledované pokusné varianty zpracování půdy (I. klasická orba na hloubku 20 až 24 cm, II. omezené zpracování půdy talířovým nářadím, III. setí do nezpracované půdy) ovlivnily fyzikální vlastnosti půdy. Varianta I vykázala za čtyřleté sledování určitou tendenci ke zhutnění půdy (objemová hmotnost vzrostla z 1,31 na 1,38 $g.cm^{-3}$). Hodnoty objemové hmotnosti ornice u variant zpracování půdy II a III výrazně stouply na 1,48 až 1,49 $g.cm^{-3}$. Na variantách II a III byla pórovitost v rozmezí 43,2 až 43,7 % obj., minimální vzdušnost 9,3 až 10,2 % obj. a maximální kapilární vodní kapacita 31,9 až 34,0 % obj. Co se týká fyzikálních vlastností půdy, nedošlo k jejich zhoršení do té míry, že by negativně ovlivnily růst, vývoj a konečnou produkci pěstovaných obilnin. Byla provedena analýza variance pro vybrané fyzikální charakteristiky půdy. Výnosy zrna kukuřice a ozimé pšenice ve čtyřletém osevním sledu jsou uvedeny jako průměry ročníků ve vztahu k variantě zpracování půdy mimo sled 1 (varianta III, statisticky neprůkazné). Obdobné výsledky byly získány v případě produkce slámy sledovaných obilnin.

Klíčová slova: ozimá pšenice, kukuřice na zrno; osevní sled; zpracování půdy; fyzikální vlastnosti půdy; výnos

ÚVOD

Zpracování půdy patří v našich podmínkách k nejvýznamnějším, avšak technologicky a energeticky nejnáročnějším operacím rostlinné produkce. O významu a náročnosti zpracování půdy svědčí i fakt, že z celkového množství spotřebovaných pohonných hmot v zemědělských podnicích připadne cca 30 % na zpracování půdy.

Nedostatek finančních prostředků v zemědělství včetně nízkého zhodnocování vkládaného kapitálu vede k nutnému omezování vstupů, k němuž patří mimo jiné i úspory pracovních a materiálových nákladů v oblasti zpracování půdy. Snaha o snížení nákladů v oblasti rostlinné produkce vede v současné době k zavádění minimalizačních prvků ve zpracování půdy. Je však třeba ověřit, zda dlouhodobější minimalizace zpracování půdy na stejném stanovišti neovlivní negativně úrodnost půdy a neprojeví se snížením produkce pěstovaných plodin.

Výzkum systémů zpracování půdy a jejich zavádění do praxe má dlouhou tradici a je realizován na celém světě, o čemž svědčí řada vědeckých prací. V našich podmínkách byl na základě modelových pokusů (Straňák, 1967) zjištěn přímý vztah mezi objemovou hmotností půdy a výnosem zrna obilnin. Vliv dlouhodobého působení různého zpracování půdy na výrobnost osevních postupů v polních pokusech prokázal Suškevič (1992). Podobnou problematikou v zahraničí se zabývali např. Pekrun, Claupein (1998).

MATERIÁL A METODY

Polní pokusy byly realizovány v letech 1990 až 1993 na bývalém pracovišti VÚZA Hrušovany u Brna, které se nachází ve výrobním typu kukuřičném. Půdní typ představuje černozem hnědozemní, půdotvorný substrát jsou neogenní sedimenty, které byly později překryty pleistocenními pokryvy spraše. Jde o půdy hluboké, přirozeně úrodné, zrnitostně hlinité, půdní reakce je neutrální. Srážkové a teplotní poměry v místě pokusu jsou uvedeny v tab. I.

Pokus byl uspořádán metodou znáhodněných bloků ve čtyřech opakováních. Sklizňová plocha jednotlivých parcel činila 27 m^2. Pokusné plodiny byly kukuřice na zrno pěstovaná po kukuřici a ozimá pšenice ve zdvojeném sledu po kukuřici na zrno. Na všech parcelách bylo hnojeno jednotně. K prvé kukuřici byla zaorána pšeničná sláma v množství 4,5 $t.ha^{-1}$ a prasečí kejda v dávce 50 $t.ha^{-1}$. Současně byla do půdního profilu zaorána průmyslová hnojiva pro celý čtyřletý pokusný sled (v čistých živinách na 1 ha: 140 kg N, 176 kg P_2O_5 a 361 kg K_2O) v podobě síranu amonného, superfosfátu a draselné soli. Ke kukuřici ve druhém sledu byla ke hnojení využita kukuřičná sláma a dávka hnojiva 220 kg $N.ha^{-1}$ (jako síran amonný). Následná pšenice byla přihnojena pouze 20 kg $N.ha^{-1}$ (na jaře, ledek).

I. Srážkové a teplotní poměry Hrušovan u Brna – Precipitation and temperature conditions of Hrušovany u Brna

Rok[1]	Roční úhrn srážek[2] (mm)	Průměrná roční teplota[3] (°C)
1955–1989	471,5	9,1
1990	510,5	10,5
1991	478,0	8,9
1992	418,4	10,2
1993	460,1	9,3

[1]year, [2]yearly sum of precipitation, [3]average yearly temperature

Pšenice po pšenici byla přihnojena pouze dávkou 100 kg N.ha^{-1} před setím (jako síran amonný). Plodiny byly u všech variant zpracování půdy jednotně ošetřeny herbicidy podle platné metodiky pro ochranu rostlin. Na vzrostlý výdrol ozimé pšenice a plevele byl použit přípravek Roundup (3 l.ha^{-1}). Ozimá pšenice byla ošetřena proti plevelům přípravkem Aminex (3 l.ha^{-1}). Do kukuřice na zrno byl aplikován přípravek Dual (3 l.ha^{-1}).

Zpracování půdy v rámci osevního sledu: 1. kukuřice na zrno, 2. kukuřice na zrno, 3. ozimá pšenice, 4. ozimá pšenice bylo realizováno ve třech variantách s různou intenzitou kypření. Varianta I: u všech plodin čtyřletého osevního sledu byla uplatněna orba. Varianta II: orba byla uplatněna pouze k první kukuřici, ke druhé kukuřici a ve zdvojeném sledu ozimých pšenic bylo omezené zpracování provedeno talířovým nářadím. Varianta III: orba byla uplatněna pouze k první kukuřici, talířové nářadí pro druhou kukuřici a ve zdvojeném sledu ozimých pšenic bylo provedeno bezorebné setí. Orba ke kukuřici proběhla na hloubku 0,24 m, k ozimé pšenici na hloubku 0,20 m, vždy radličným pluhem. K omezenému zpracování půdy ke kukuřici na hloubku 0,15 m a k ozimé pšenici na hloubku 0,12 m byl použit talířový podmítač.

Pro zachycení vlivu dlouhodobého působení intenzity zpracování půdy na fyzikální vlastnosti půdy byly odebrány v roce 1989 a 1993 vzorky půdy u všech variant zpracování půdy z hloubky 0 až 0,10 m, 0,10 až 0,20 m a 0,20 až 0,30 m. Statistické hodnocení bylo provedeno analýzou variance (software MS Excel-Anova). Analýza variance ortogonálního pokusu při trojném třídění byla založena na testování variance pokusných faktorů (tři varianty, dva ročníky, tři hloubky stanovení) a vzájemné interakce všech těchto faktorů se zbytkovou variancí, tj. variancí trojnásobné interakce a x b x c. Výsledky pak lze interpretovat jako testování významnosti vlivu faktorů a dvojnásobných interakcí ve srovnání s trojnásobnou interakcí.

VÝSLEDKY A DISKUSE

Analýza variance naměřených hodnot vybraných fyzikálních charakteristik půdy (tab. II) neprokázala u většiny sledovaných charakteristik významný vliv faktorů ani jejich interakcí na jejich úroveň. Objemová hmotnost ani celková pórovitost nebyly pokusnými podmínkami ovlivněny. Momentální obsah vody byl vysoce významně ovlivněn ročníkem, hloubkou stanovení a interakcí sledovaných variant s ročníkem. Vyšší obsah byl zaznamenán v roce 1993, což bylo dáno vyššími srážkami na podzim tohoto roku než na jaře 1989. Vyšší hodnoty byly zjištěny ve větší hloubce půdy. Interakce ročníku s variantou byla v roce 1989 u druhé varianty (omezené zpracování půdy) nejnižší, zatímco v roce 1993 byla nejvyšší, což lze vysvětlit významným zvyšováním maximální kapilární kapacity, která byla v roce 1993 nejvyšší u této varianty.

Momentální obsah vzduchu v půdě byl významně ovlivněn ročníkem. V roce 1993, kdy byly před odběrem vzorku zaznamenány dešťové srážky, byl nižší. V roce 1989, kdy byla vlhkost půdy nižší, byl naopak vyšší. Např. ve variantě s omezeným zpracováním půdy činil v roce 1993 v průměru celé hloubky stanovení jen 16,0 % obj., kdežto v roce 1989 ve stejné variantě 31,2 % obj.

Pokusným uspořádáním byla nejvíc ovlivněna maximální kapilární kapacita půdy, a to významně variantami, hloubkou stanovení, interakcí varianty s ročníkem a interakcí hloubky stanovení s ročníkem. Nejvyšší MKK byla zaznamenána u varianty II (33,85 % obj.), nejnižší u varianty orané (32,35 % obj.). V průměru dosáhla MKK nejvyšší hodnoty u varianty II (33,48 % obj.), nejnižší u varianty bez zpracování půdy (32,73 % obj.). Interakce ročníku s variantou vyplývá ze skutečnosti, že na počátku pokusu byla u varianty bez zpracování půdy 32,6 % obj. a při ukončení pokusu u varianty orané činila 31,9 % obj. Na počátku pokusu byla v hloubce

II. Analýza variance pro vybrané fyzikální charakteristiky půdy – Analysis of variance for choiced physical parameters of soil

Zdroje proměnlivosti[1]		dF	MS					
			objemová hmotnost[2]	celková pórovitost[3]	momentální obsah vody[4]	momentální obsah vzduchu[5]	maximální kapilární kapacita[6]	minimální vzdušná kapacita[7]
Varianta zpracování půdy[8]	a	2	0,0162	15,08	4,82	24,38	3,376**	29,53
Ročník[9]	b	1	0,0374	58,68	268,35**	691,92**	0,056	60,87
Hloubka stanovení[10]	c	2	0,0172	27,62	26,74**	91,61	0,851*	29,87
Interakce[11] a x b		2	0,0012	2,48	7,92*	14,62	1,429*	3,03
a x c		4	0,0043	6,20	1,13	19,48	0,269	8,87
b x c		2	0,0027	4,54	3,13	12,74	0,867*	4,96
Reziduum[12] (interakce a x b x c)		4	0,0059	9,16	1,02	14,69	0,086	10,12
Celkem[13]		17	–	–	–	–	–	–

* $P \leq 0,05$
** $P \leq 0,01$

[1]sources of variability, [2]volume weight, [3]total porosity, [4]momentary water content, [5]momentary air content, [6]maximal capillary capacity, [7]minimal air capacity, [8]variant of soil cultivation, [9]year, [10]soil depth volume, [11]interaction, [12]residue, [13]sum

III. Produkce zrna kukuřice a ozimé pšenice ve čtyřletém osevním sledu podle variant zpracování půdy v letech 1990 až 1993 (t.ha^{-1}) – Seed production of grain maize and winter wheat in a four-year seeding sequence according to soil management variants in 1990 to 1993 (t.ha^{-1})

Předplodina[1]	Zpracování půdy[4]	1990			1991			1992			1993			Průměr[8] (1990–1993)		
		orba[5]	omezené zpracování[6]	bez zpracování[7]	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování
Pšenice[2]	kukuřice	4,59	4,12	5,53	7,91	7,98	9,00	4,86	5,53	5,95	5,43	4,69	5,79	5,70 a b	5,58 a	6,57 b
Kukuřice[3]	kukuřice	5,58	5,02	4,59	8,35	8,19	8,15	4,64	5,10	4,65	7,16	7,30	7,38	6,43 a	6,40 a	6,19 a
Kukuřice	pšenice	7,27	7,20	7,3	7,58	6,75	7,46	3,67	3,96	4,18	5,63	6,02	5,79	6,04 a	5,98 a	6,19 a
Pšenice	pšenice	5,39	5,54	5,88	5,92	6,15	5,72	4,42	4,41	4,39	5,50	5,57	5,06	5,31 a	5,42 a	5,26 a

Diference označené různými písmeny jsou statisticky významné při $P \leq 0{,}01$ – Means with different letters are statistically significant at $P \leq 0.01$
P (0,01) = 0,91

[1]pre-crop, [2]wheat, [3]maize, [4]soil cultivation, [5]tillage, [6]limited cultivation, [7]without cultivation, [8]mean

IV. Produkce slámy kukuřice a ozimé pšenice ve čtyřletém osevním sledu podle variant zpracování půdy v letech 1990 až 1993 (t.ha^{-1}) – Straw production of grain maize and winter wheat in a four-year seeding sequence according to soil management variants in 1990 to 1993 (t.ha^{-1})

Předplodina[1]	Zpracování půdy[4]	1990			1991			1992			1993			Průměr[8] (1990–1993)		
		orba[5]	omezené zpracování[6]	bez zpracování[7]	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování	orba	omezené zpracování	bez zpracování
Pšenice[2]	kukuřice	6,94	5,58	8,40	6,46	6,29	8,48	6,25	6,93	7,21	8,92	7,48	12,94	7,14 a	6,57 a	9,26 b
Kukuřice[3]	kukuřice	7,22	6,63	4,59	7,08	7,51	7,97	5,68	6,32	6,26	9,02	8,98	11,34	7,25 a	7,36 a	7,54 a
Kukuřice	pšenice	4,29	3,01	3,36	9,07	8,74	8,95	2,44	2,78	2,92	3,43	3,66	3,22	4,81 a	4,55 a	4,61 a
Pšenice	pšenice	3,60	2,60	3,80	7,06	6,37	7,36	3,77	3,85	3,83	3,81	3,55	2,82	4,56 a	4,09 a	4,45 a

Diference označené různými písmeny jsou statisticky významné při $P \leq 0{,}01$ – Means with different letters are statistically significant at $P \leq 0.01$
P (0,01) = 1,89

For 1–8 see Tab. III

0,1 až 0,2 m 33,9 % obj., po ukončení ve svrchní vrstvě 0 až 0,1 m činila 33,3 % obj.

Poznatky řady zahraničních i našich autorů potvrzují, že obilniny pro svůj optimální růst a vývoj vyžadují utuženější půdu, jejíž fyzikální stav se blíží půdě neorané (Suškevič, 1995). Ke stejným závěrům došli i Hrubý (1993) a Kňákal et al. (1997). Někteří zahraniční autoři (Carter, Steed, 1992; Pekrun, Claupein, 1998) sledovali objemovou hmotnost vrchní vrstvy půdy též v souvislosti s ekonomikou zpracování půdy.

Hodnotíme-li výnosy zrna kukuřice a ozimé pšenice ve čtyřletém osevním sledu (tab. III), byla produkce zrna ovlivněna třemi faktory: ročníkem, postavením ve sledu plodin a variantou zpracování půdy.

Vliv ročníku se v letech vedení pokusu 1990 až 1993 projevil na výnosech zrna kukuřice a ozimé pšenice bez ohledu na varianty zpracování půdy významně a souvisel s průběhem povětrnostních faktorů během vegetace. V tomto ohledu lze za nejpříznivější pro kukuřici považovat roky 1991 a 1993, nepříznivý byl rok 1990. Pro pšenici byly povětrnostně příznivé roky 1990 a 1991, nepříznivý byl rok 1992.

Dalším faktorem, který ovlivnil výnosové výsledky kukuřice na zrno a ozimé pšenice, bylo zařazení plodin v osevním sledu. Vyšší výnos zrna kukuřice byl zaznamenán ve sledu 2. Za příčinu považujeme pozitivní působení první širokolisté plodiny ve zdvojeném sledu, v daném případě předplodiny kukuřice na kukuřici. Organicky hnojená kukuřice je plodina nenáročná na předplodinu a krátkodobé pěstování kukuřice po sobě je běžná zemědělská praxe.

Nejvyšší výnos zrna ozimé pšenice byl dosažen ve sledu 3, kdy byla ozimá pšenice pěstována po zdvojeném sledu kukuřice. Ve sledu 4, kdy byla pěstována ozimá pšenice po ozimé pšenici byl výnos nižší. Důvodem jsou všeobecně vyšší nároky ozimé pšenice na předplodinu.

Třetí faktor (varianta zpracování půdy) ovlivnil produkci zrna kukuřice a ozimé pšenice nejméně. Zjištěné výnosy byly vyrovnané, rozdíly minimální, statisticky neprůkazné, vyjma výnosu kukuřice ve sledu 1 (varianta III).

Výsledky sledování vlivu ročníku a varianty zpracování půdy metodou analýzy rozptylu byly na hladině průkaznosti ve sledu 1 (varianta III) 99,71 %. Neprůkaznost ostatních variant může mít příčinu mimo jiné i ve vysoké přirozené úrodnosti půdy, která na pokusném stanovišti setřela výnosové rozdíly mezi sledovanými variantami zpracování půdy, dále pak i v poměrně vysoké úrovni výživy pokusných plodin. Uplatnění minimalizačních prvků při zpracování půdy k zrnové kukuřici a ozimé pšenici na variantách II a III ve srovnání s variantou I (orba + tradiční zpracování půdy) se neprojevilo na produkci zrna těchto plodin ani pozitivně, ani negativně. Obdobné výsledky byly potvrzeny i v případě dosažené produkce vedlejších produktů slámy kukuřice a ozimé pšenice (tab. IV). Získané výsledky korespondují s údaji z literatury (Suškevič, 1994), které při použití minimalizačních technologií v sušší kukuřičné oblasti neprokázaly ve srovnání s orbou průkazné diference ve výnosech zrna ozimé pšenice, jarního ječmene ani kukuřice.

Hlavní význam minimalizačních prvků při zpracování půdy lze tedy spatřovat v jejich ekonomickém přínosu, dosaženém úsporami pracovních a materiálových nákladů. Další výhodou minimalizace zpracování půdy a setí do nezpracované půdy je podstatné zkrácení intervalu mezi později sklizenou předplodinou a osevem ozimé obilniny a zasetí v agrotechnické lhůtě. Omezením orby, kterou lze považovat za energeticky nejnáročnější úkon ve zpracování půdy, lze významně snížit vstupy do rostlinné výroby.

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OLD ENVIRONMENTAL LOADS AND THEIR IMPACTS ON THE QUALITY OF GROUNDWATERS AND SOILS

STARÉ ZÁTĚŽE A JEJICH VLIV NA KVALITU PODZEMNÍCH VOD A ZEMIN

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ABSTRACT: Impacts of old environmental loads on the quality of groundwaters and soils were studied in Northern Bohemia, on the grounds of an engineering firm that is a typical production unit of similar type in the CR for its production activities. Tetrachloroethylene (PCE), trichloroethylene (TCE), dichloroethylene (DCE) and nonpolar extractable compounds (NEC) were demonstrated to be main contaminants after processing of data (from 1992 to 1997) on soil, groundwater and soil air samples in which organic and inorganic xenobiotic compounds were investigated. Heavy metals were present at lower concentrations. The mechanism of NEC contamination is influenced by the environment (surface and ground waters, soil, soil air), as for the mechanism of contamination with aliphatic chlorinated hydrocarbons, migration is influenced by their properties and environmental characteristics.

Keywords: old environmental loads; rock environment; chlorinated and petroleum hydrocarbons; heavy metals

ABSTRAKT: Vliv starých zátěží na kvalitu podzemních vod a zemin byl sledován v severních Čechách v areálu strojírenského podniku, který typem výrobní činnosti patří mezi charakteristické výrobní jednotky podobného druhu v ČR. Vyhodnocením údajů (za období 1992 až 1997) vzorků zemin, podzemních vod a půdního vzduchu, ve kterých byly sledovány organické i anorganické xenobiotické látky, bylo prokázáno, že hlavními kontaminanty jsou tetrachlorethylen (PCE), trichlorethylen (TCE), dichlorethylen (DCE) a nepolární extrahovatelné látky (NEL), v menší míře pak vybrané těžké kovy. Mechanismus kontaminace u NEL je závislý na prostředí (povrchové a podzemní vody, zemina, půdní vzduch), u mechanismu alifatických chlorovaných uhlovodíků je migrace závislá na vlastnostech a charakteristice prostředí.

Klíčová slova: staré zátěže; horninové prostředí; chlorované a ropné uhlovodíky; těžké kovy

INTRODUCTION

The effect of old environmental loads on the quality of rock environment was studied in an interest area (the grounds of an industrial firm in North Bohemia) with a long-term load of industrial production. Chip working, manufacture of parts made of metal for brake systems, pistons, pins, rods, etc., have historically been the main industrial activities. Metal sections, metal sheets manufactured on the basis of iron and aluminium were used as raw materials. Working operations involved e.g. degreasing, metal working, passivation and hauling.

Long-term production activities and handling of petroleum and chlorinated hydrocarbons caused groundwater and soil contamination with heavy metals, petroleum and chlorinated hydrocarbons. Remediation of contaminated lands (scrap yard and bedrock of inflammables depot) was decided in 1992, contaminated soil from the scrap yard was extracted and hauled away in 1993. The excavation was filled with inert material. A drainage system was built in the bedrock, consisting of conduits conveying fluids to a drained off pit.

Groundwater under the inflammables depot contaminated with chlorinated hydrocarbons was remediated by stripping in 1992. The process of remediation was slow due to the little pervious bedrock, therefore the methods *in situ* and *ex situ* were combined (Deckwer, Weppen, 1987).

Groundwater contamination with polychlorinated and petroleum hydrocarbons in the area concerned was demonstrated by the results of laboratory analyses with respect to the used production technology.

It is especially water solubility that is important in view of contamination and decontamination dynamics. It cannot be determined exactly because contamination is regularly caused by a mixture of hydrocarbon compounds of different water solubility (Wittlingerová, 1998).

The goal of the paper was to evaluate the results of monitoring of groundwater quality in order to assess the efficiency of measures taken to eliminate old environmental loads in form of chlorinated or petroleum hydrocarbons.

MATERIAL AND METHODS

Investigations were carried out before the experience of surveys at such localities was formulated in general and before legislative rules and methodical procedures for risk assessment at localities of similar type were adopted.

These methods were applied at the given locality. First, all available archival information was evaluated. Following the identification of potential foci of contamination atmogeochemical methods were used. Atmogeochemical probes were used to search for and to localize the foci of contamination: contents of volatile substances in soil air were determined in shallow probes under field conditions, cumulative volatile substances were measured with gasometers. The atmogeochemical and gasometric measurements demonstrated outlasting soil contamination with chlorinated and petroleum hydrocarbons. Sampling probes were bored at the identified sites. Three holes were bored to take samples for analyses of the quality of soils, groundwaters and soil air. Mixed soil samples were taken from the cores at one meter distances, and they were analyzed for the content of petroleum hydrocarbons (PH) by infrared spectroscopy while the content of heavy metals (HM) was determined from extracts in 2M HNO_3. The contents of soil contaminants determined in a laboratory were compared with the values established in accordance with A Methodical Instruction of Ministry of the Environment of the Czech Republic (Criteria of Soil and Groundwater Contamination). Special attention was paid to samplings of groundwaters because they were one of the important migration paths. Samples were taken at a dynamic state, i.e. after a short-time groundwater pumping out. Thickness of the layer of petroleum hydrocarbons was measured prior to sampling. E.g. a layer of petroleum product in the borehole Pit ranged from 5 to 10 cm. A proposal of remedial measures at the given locality was devised after evaluation of all hydrogeological and hydrochemical data, and the use of air extraction technology (venting) was proposed. A one-month venting test started probably for the first time in the CR in the fall 1993, under a scheme like this: soil air was drawn with a vacuum pump from one probe and the concentration of undesirable compounds was estimated in sorption tubes. A total of 36 kg chlorinated hydrocarbons (ClH/month) and 10 kg of petroleum hydrocarbons (PH/month) was extracted during the test. These values were calculated from recorded concentrations of these compounds in drawn air. Taking into account venting efficiency, remediation of waters by pumping was interrupted and it was decided to start remediation of the aeration zone by air extraction. Three probes were bored to take soil samples; samples at a 1m distance were taken in each probe.

Evaluation of all probes was focused on potentially harmful substances that can occur in engineering firms of similar type, i.e. on chlorinated and petroleum hydrocarbons, and on some heavy metals (Pb, Cu, Cd, Zn, Ni, Cr).

RESULTS AND DISCUSSION

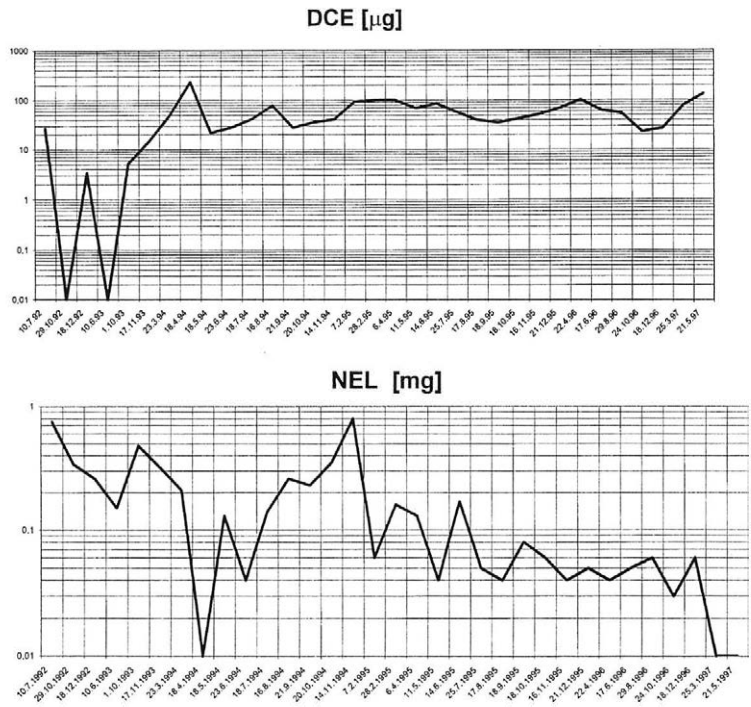
Nonpolar extractable compounds (NEC) and chlorinated hydrocarbons (ClH) are the main contaminants at the locality concerned. The mechanism of NEC contamination is related to the environment represented by surface waters, groundwaters, soil, soil air. As for the mechanism of contamination with aliphatic chlorinated hydrocarbons (TCE, PCE, DCE), their properties and environmental characteristics are responsible for the main paths of their migration and spreading. Their migration is determined by their high volatility and density, higher than water density. Among the characteristics of the rock environment, limited perviousness of the mantle rock (eluvium) results in contamination accumulation and retardation of transport to the groundwater table including a subsequent migration along the base of impervious stratum (granite).

Evaluation of groundwater contamination

Chlorinated hydrocarbons on the grounds of an engineering firm. Heavy contamination under the inflammables depot was demonstrated by analyses of samples from boreholes HV2, HV3, PB2. Borehole HV3: max. 4 165 µg/l in 1992, 18 960 µg/l ClH in 1993. Samplings from 1994, 1995, 1996, 1997 document a decrease in contamination as a result of remedial measures. Samples from a pit under the scrap yard were taken for the first time in March 1994, and high DCE contents were recorded. As the source of contamination was unclear, samples were taken from borehole A1 in front of an automatic metal working plant. The borehole is situated above the scrap yard and pit, i.e. upstream of the groundwater flow. A concentration of 24 100 µg/l DCE was determined. The automatic metal working plant was likely to be a source of contamination. Variations in ClH contents were observed in the pit. The values showed a decreasing trend in 1996 and 1997. The values for borehole HV2 showed an expressively decreasing trend in the years 1992, 1994, 1995, 1996 and 1997.

Heavy metals on the grounds of an engineering firm. Contents of Cu, Pb, Cd, Zn, Ni, Cr were monitored. Results for the years of observation: higher contents of Zn were recorded – the values ranged between category B and C in borehole HV3 in 1994. Category B was exceeded once in samples from borehole HV2 in 1994. Increased contents of Pb in category B values were determined twice in borehole HV3 in 1994, once in borehole HV2 in 1994 and 1995. Category B was exceeded three times in Cd samples from borehole HV3 in 1994, once in 1995. Category B was exceeded once in borehole HV2 in 1995. Occurrence of Ni and Cr was sporadic, and was not proved by subsequent samplings. Sporadic occurrence of Cu in category C was observed in borehole HV2, and in category B in borehole HV3.

Chlorinated hydrocarbons at the exit from the grounds of an engineering firm. The highest content of DCE was determined in water samples from borehole PB2. Fluctuating increases in concentrations in category B, C were evident in 1994, 1995, 1996, 1997. A substantial decrease in nonpolar extractable compounds (NEL) was documented at the exit from the grounds of the firm since November 1994 (Fig. 1).



1. Frequency of DCE and NEL concentrations in borehole PB2

Heavy metals at the exit from the grounds of an engineering firm. Increased concentrations of Cu, Pb, Cd were determined in water samples from borehole PB2; category C limit was exceeded twice and category B limit four times in Cu and Pb concentrations, category C limit was exceeded once and category B limit three times in Cd concentrations. The limit values of Zn, Ni and Cr concentrations were not exceeded in any case over the years of observation. In none of the cases has the limit content of elements in category A been exceeded since 16th November 1995. It documents intermittent fluctuations in concentrations of some HM in water in some years, but contamination has died away. The results indicate that the contamination of groundwaters with Cu, Pb, Cd at the exit from the grounds of the firm was higher in some years than the values recorded in probes within the grounds of the firm; it can partly be explained by a distance of the borehole from the grounds of the firm (a lag of groundwater reach between the profiles).

Evaluation of soil contamination in some boreholes

Three boreholes were made in the area of the former scrap yard, inflammables depot and automatic metal working plant to take soil samples for monitoring of some HM and PH. PH contaminations in boreholes no. 1 and 3 were documented by analyses (in the scrap yard and inflammables depot, samples taken in 1992). Medium to high contamination of soils with petroleum hydrocarbons was demonstrated (mainly in the layers nearer to the ground surface). Contamination of category B was demonstrated at a depth of 0 to 1 m in borehole no. 1 and of category C at a depth of 1 to 2 m. Borehole no. 3 showed contamination of category C at 0 to 1 m and of category B at 2 to 2.6 m. Borehole no. 2 was free of contamination. The contents of all monitored elements (HM) in all boreholes were included in category A in accordance with the instruction of Ministry of the Environment, showing explicitly that the soil was not contaminated in the interior of the firm; it also explains HM contents in groundwaters corresponding to category A in agreement with the cited criteria of Ministry of the Environment. Heavy contamination with petroleum hydrocarbons was demonstrated in the environs of the scrap yard and inflammables depot (up to 3.10^4 mg/kg). As the contents of petroleum hydrocarbons in soil and groundwater were high, biodegradation by the Ropstop method was proposed in 1992. But the soil decontamination did not have any desirable effects, therefore 282 m^3 of soil were extracted on the area of 188 m^2 to a depth of 1.5 m.

CONCLUSION

Ex situ remediation was effective in comparison with *in situ* remediation. It is not possible to achieve a permanent remediation effect without elimination of contamination under the separate buildings (Brückner et al., 1986). Little conclusive results are provided by at-

mogeochemical methods applied to built-up heavily contaminated localities. An important reduction of risk was achieved by combination of remediation and reconstruction measures. The remedial limits should be higher than those recommended by the instruction (Criteria of Ministry of the Environment, 1996), particularly at the localities where petroleum compounds are handled.

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INFLUENCE OF SELENIUM ON THE YIELD AND QUALITY OF CHAMOMILE [*CHAMOMILLA RECUTITA* (L.) RAUSCH.]

VLIV SELENU NA VÝNOS A KVALITU HEŘMÁNKU [*CHAMOMILLA RECUTITA* (L.) RAUSCH.]

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ABSTRACT: The influence of the different doses of selenium (Se) on the yield and quality of chamomile [*Chamomilla recutita* (L.) Rausch.] was investigated. Special attention was paid to the essential oil content, as well as to the mutual relationship between some of the oil components (chamazulene, bisabolol, bisabolol oxide). Se was applied by foliar spraying, ten days before the harvest, as the Na_2SeO_4 solution, in the following doses: 0, 100 and 500 g Se/ha. It was found that the applied doses of Se did not influence the formation of dry chamomile flowers yield. Also, the influence of Se on the content of essential oil was not observed (average oil content in all treatments was 0.33%). However, the applied Se caused the significant increase of the content of bisabolol oxide A and B, followed by the decrease of the chamazulene content in the chamomile essential oil. Beside that, significant increase of Se content in the chamomile flowers (12.9 to 53.6 ppm) has also been observed.

Keywords: selenium; chamomile; yield; essential oil; chamazulene; bisabolol; bisabolol oxide

ABSTRAKT: Byl sledován vliv různých dávek selenu (Se) na výnos a kvalitu heřmánku [*Chamomilla recutita* (L.) Rausch.]. Zvláštní pozornost byla věnována obsahu silic a zejména vzájemnému vztahu mezi některými jejich složkami (chamazulen, bisabolol, bisabolol oxid). Se byl aplikován foliárně postřikem deset dní před sběrem, stejně tak roztok Na_2SeO_4 v dávce 0, 100 a 500 g Se/ha. Bylo zjištěno, že aplikované dávky Se neměly vliv na výnos sušiny květů. Rovněž nebyl pozorován vliv Se na obsah silic (průměrný obsah silic ve všech variantách byl 0,33 %). Aplikovaný Se způsobil značný nárůst obsahu bisabolol oxidu A a B a pokles obsahu chamazulenu. Kromě toho byl pozorován významný nárůst obsahu Se v květech heřmánku (12,9 až 53,6 ppm).

Klíčová slova: selen; heřmánek; výnos; silice; chamazulen; bisabolol; bisabolol oxid

INTRODUCTION

One of the recent activities in the Institute for Medicinal Plant Research Dr. Josif Pančić (Belgrade, Yugoslavia) is enrichment of some medicinal plants with selenium (Se), in order to improve their utility in the phytopreparations (Jakovljević et al., 1996; Sekulović et al., 1996). Since the soils in our country are characterized by the deficiency of Se (Maksimović et al., 1989), the produced food cannot fully satisfy man's daily needs for this element (100 to 200 μg). Tea and other phytopreparations based on the medicinal plants enriched with Se could significantly increase its daily input. Previous research revealed that Se application as fertilizer significantly increased its content in the investigated medicinal plants: nettle, chamomile, peppermint (Jakovljević et al., 1996; Sekulović et al., 1996). However, this opened a question about effect of Se on the quality and metabolism of the investigated plants, since rather high doses of Se (100 and 500 g/ha) were applied in quoted works. For this reason our paper presents the effect of different doses of Se on the chamomile yield and essential oil content. Special attention has been paid to the chemical composition of essential oil from chamomile enriched with Se, since utility of chamomile in the pharmacy and cosmetics is primarily based on some of the active components of the essential oil.

MATERIAL AND METHODS

The field production experiment with chamomile [*Chamomilla recutita* (L.) Rausch.], cultivar Banatska, was carried out during 1997 in Pančevo (experimental field of the Institute for Medicinal Plant Research) on humogley soil. Se was applied by foliar spraying, ten

days before the harvest, as the Na_2SeO_4 solution, in the following doses: 0, 100 and 500 g Se/ha. Sampling of the chamomile flowers was carried out during the harvest, in four replications per each variant, from the elementary parcels of 9 m^2.

After the harvest chamomile flowers were dried at 40 °C, with ventilation, to avoid any losses of essential oil. The essential oil content was determined by hydrodistillation of dried material in the Clevenger type apparatus, according to Ph. Jug IV (1984), while composition of the essential oil was determined by gas chromatography (CG-FID and CG-MS technique).

Se content in the chamomile flowers was also determined, after drying at 70 °C and grinding. The samples were subjected to wet digestion with the mixture of nitric and perchloric acid, with the addition of H_2O_2. Se content was then determined by using hydride generation AAS, after reduction of Se (VI) to Se (IV) with 6M HCl (heating at 90 °C for 30 minutes).

The similar method was applied to determine the Se content in prepared ethanol and water extracts of chamomile flowers at the ratio of 1 : 1 and 1 : 62.5, respectively.

RESULTS AND DISCUSSION

The yield of the dry chamomile flowers, obtained in this study, corresponds to the average values for our country (Stepanović, 1983). On the bases of the results presented in Tab. I, it can be stated that applied doses of Se did not influence the formation of dry chamomile flowers yield. Nevertheless, it was observed that the higher dose of Se (500 g/ha) had caused, in some extent, the decrease of yield, compared with the control (about 5%). However, observed decrease of yield was not statistically significant, so it was probably a consequence of mechanical tissue injuries, caused by the high concentration of the applied Se solution. In order to realize the influence of Se on the chamomile yield more precisely, in a future research it is necessary to make a longer time interval between the application of Se and the harvest, including lower doses of Se.

I. Influence of selenium on chamomile yield and essential oil content

Se dose (g/ha)	$\bar{x}$	100	500
Chamomile yield (g/ha dry matter)	720	750	690
Essential oil content (%)	0.33	0.32	0.33
Se content in chamomile flowers (ppm)	0.14	12.9	53.6

Obtained essential oil content in the dry chamomile flowers (0.3%, Tab. I) is relatively low (below the value of 0.4%, according to Ph. Jug IV, 1984). The content and quality of the essential oil depend on the great number of factors – origin of chamomile, development stage of a plant, genetic factors, growing conditions, drying conditions, etc. (Felklová et al., 1982; Figueiredo et al., 1996; Tasić, 1997). Other authors (Krstić-Pavlović, Džamić, 1983; Mihajlov, 1988; Vukomanović, 1992; Mihajlov, 1997) also pointed out that in a great number of our habitats, especially under unfavorable conditions, required quantity of essential oil in the chamomile flowers was not achieved. In this study, essential oil content was uniform in all variants, in other words negative influence of applied Se was not observed. Such data are of a great importance, since in case of peppermint the decrease of essential oil content was observed yet with lower Se dose (100 g/ha) (Maksimović et al., 1999). Further research should include a lower Se doses (< 100 g/ha) and/or longer period between the application of Se and chamomile harvest.

Besides the total Se content in the soil was very low (0.200 ppm), its content in chamomile flowers (Tab. I) in the control, although relatively low, was within optimum values for plant material (0.1 to 1 ppm). This points out a possibility that chamomile might represent a culture which highly accumulates this element, since deficiency of Se for plants may occur when its total content in soil is below 0.500 ppm (Mayland et al., 1989). The applied Se doses caused significant increase of its content in the chamomile flowers (12.9 to 53.6 ppm). This can have a satisfactory use satisfying a part of daily human needs (100 to 200 µg) in this element, in a form of tea or some other phytopreparations produced from such substance, specially because customary nutrition in our country supplies only about 30% of daily human needs (Djujić et al., 1995). Based on data in Tabs. I and II it can easily be calculated that a cup of chamomile tea (4 g/250 ml) enriched with Se by a lower Se dose provides an intake of 10 to 20 µg Se. Chamomile enriched with Se by the higher Se dose can be used in the same way, after mixing with normal plants in the ratio 1 : 5. Nevertheless, if it is used for tea making directly, then a cup of tea would provide even about 80 µg Se, but such consumption should be confirmed through medical research.

Although Se content in the chamomile has reached its toxical values for plant material (> 5 ppm, Kabata-Pendias, Pendias, 1989) after foliar treatment with Se fertilizer, it is of special importance that Se is present in organic compounds (different amino acids) in enriched chamomile, as well as in the tea from such substance row, therefore in the forms which are not toxic to humans. This statement can bee seen from the very low Se content in the ethanolic extracts (Tab. II).

II. Selenium content in water and ethanolic extract from chamomile flowers (in % of total Se found in plant)

Se dose (g/ha)	Water extract	Ethanolic extract
$\bar{x}$	37.5	4.1
100	38.0	4.6
500	42.0	4.1

III. Influence of selenium on the chemical composition of the chamomile essential oil

Component (%)	Treatment			Signification of difference between		
	$\bar{x}$	Se-1	Se-2	$\bar{x}$ Se-1	$\bar{x}$ Se-2	Se-1/Se-2
trans-β-Farnesene	17.29	9.42	10.89	*	*	–
Germacrene D	1.23	0.65	0.67	*	*	–
Bicyclogermacrene	0.51	0.35	0.40	–	–	–
trans, trans-α-Farnesene	0.61	0.30	0.33	*	*	–
Spathulenol	2.09	1.50	1.62	–	–	–
Bisabolol oxide B	15.32	23.33	23.19	*	*	–
Bisabolol oxide + α-bisabolol	8.91	11.72	11.50	*	*	–
Chamazulene	10.97	7.93	8.77	**	*	–
Bisabolol oxide A	27.04	31.99	29.15	**	–	*
cis-en-in-Dicycloether	14.23	10.43	10.71	–	–	–
trans-en-in-Dicycloether	1.78	2.34	2.74	–	–	–

** significant at probability level of 0.01
* significant at probability level of 0.05
– not significant

According to mutual relationships between an important essential oil components in the control (Tab. III), chamomile (cultivar Banatska) from this research belongs to type B (Schichler, 1973). After the foliar application of the lower Se dose (1 to 100 g/ha) a relatively increase of components based on bisabolol oxide (A and B) was observed in chamomile essential oil, with simultaneous decrease of chamazulene and some components based on farnesene and germacrene. Changes in relative content of components based on spiroethers (cis-en-in-dicycloether and trans-en-in-dicycloether) were not statistically significant. The application of five times higher Se dose (2 to 500 g/ha) caused the same changes in the chamomile essential oil. Nevertheless, besides of some changes in mutual relationship between some important essential oil components, they did not caused a change in the chamomile type. In a view of a fact that all of the components show certain pharmacological effect (Ugrešić et al., 1997), and that there are no available data about limits within which some components must be considered, obtained changes in the chemical composition of chamomile essential oil cannot be explained by either positive or negative influence of Se uptake. In order to preserve attained increment of bisabolol oxide-based components (if it is considered as a positive effect for some purposes), and also to prevent decrease of chamazulene content, in a future research lower Se doses (< 100 g/ha) and/or longer time period between the application of Se and chamomile harvest should be included.

CONCLUSION

This research has revealed that the foliar application of Se could significantly increase its content in the chamomile flowers, without an expression of negative influence of its uptake on chamomile yield and essential oil content. Recorded changes in the chemical composition of essential oil cannot be noted either as negative or positive ones.

Tea and other phytopreparations based on the chamomile enriched with Se in organic forms could be significant source in daily human supply with this element.

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EFFECT OF ARBUSCULAR MYCORRHIZAL FUNGI AND *TRICHODERMA HARZIANUM* ON THREE SPECIES OF BALCONY PLANTS

VLIV ARBUSKULÁRNÍCH MYKORRHIZNÍCH HUB A *TRICHODERMA HARZIANUM* NA RŮST TŘÍ DRUHŮ BALKONOVÝCH ROSTLIN

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ABSTRACT: Effects of the inoculation of rooting substrate with arbuscular mycorrhizal fungi, with *Trichoderma harzianum*, and with both microorganisms and the effect of application of fungicide Previcur were tested in an experiment with three species of balcony plants (*Verbena*, *Torenia*, *Diascia*) propagated from cuttings. Mycorrhizal inoculation significantly increased fresh weight, dry weight and total shoot length of *Verbena* plants and dry weight and total shoot length of *Torenia* plants. Mycorrhiza improved leaf colour of all three species, the greatest differences of this parameter between inoculated and uninoculated plants were found particularly before transplantation, whereas they almost diminished at the end of the experiment. *T. harzianum* had no effect on any growth parameter nor leaf colour. Plants in the treatments inoculated with both microorganisms showed similar significantly positive growth response as in the treatments inoculated with mycorrhizal fungi. Application of fungicide Previcur slightly improved leaf colour, and significantly increased total shoot length of *Torenia* plants.

Keywords: arbuscular mycorrhizal fungi; balcony plants; inoculation; horticulture substrates

ABSTRAKT: Ve skleníkových kultivačních pokusech byl sledován vliv inokulace množárenského substrátu arbuskulárními mykorrhizními houbami a preparátem s neparazitickou houbou *Trichoderma harzianum*, dvojí inokulace oběma mikroorganismy a zálivky fungicidem Previcur na růst mladých balkonových rostlin (*Verbena*, *Torenia*, *Diascia*) množených bylinnými řízky. Mykorrhizní inokulace zlepšila vybarvení listů u všech druhů, největší rozdíly oproti kontrolním rostlinám s mírně chlorotickými listy se projevily před přesazením, ke konci pokusu byly méně nápadné. Mykorrhizní inokulace měla statisticky průkazný, pozitivní vliv na čerstvou hmotnost, hmotnost sušiny, celkovou délku stonků a počet květenství u rostlin *Verbena* a na hmotnost sušiny a celkovou délku stonků u rostlin *Torenia*. Samotná inokulace s preparátem *T. harzianum* neovlinila růst ani vybarvení listů rostlin, které byly před přesazením mírně chlorotické, podobně jako listy kontrolních rostlin. Rostliny inokulované oběma mikroorganismy vykazovaly podobné statisticky průkazné pozitivní růstové reakce jako rostliny ve variantách inokulovaných pouze mykorrhizními houbami. Aplikace fungicidu Previcur mírně zlepšovala vybarvení listů, ne však tak jako inokulace mykorrhizními houbami, kromě toho měla průkazně pozitivní vliv na celkovou délku stonků u rostlin *Torenia*.

Klíčová slova: arbuskulární mykorrhizní houby; balkonové rostliny; inokulace; zahradnické substráty

INTRODUCTION

Arbuscular mycorrhizal fungi (AMF) can stimulate plant growth particularly in the soils with the low level of available nutrients (rewieved by Smith, Read, 1997). There are many references concerning growth and stress tolerance improvement of ornamental plants (Johnson et al., 1982; Nemec, 1987). Horticultural crop and flowers have been used as the host plants in several experimental tests for application of AMF (Chang, 1994). The AMF can stimulate plant growth especially in the soils with lower fertility and the positive effect of mycorrhiza on plants is mainly due to improved phosphorus and water uptake (Smith, Read, 1997). The AMF enable their host plant to tolerate environmental extremes such as P and N deficiency, drought, low pH, soil pollution, negative effects of some root pathogens etc. (Sylvia, Williams, 1992). Since the indigenous populations of mycorrhizal fungi are present in most soils, the preinoculation of seedlings in inert substrates without native mycorrhizal symbionts give the introduced fungal strain the spatial advantage over the indigenous fungi which colonize the roots during cultivation period or after transplanting of plants into the field soil (Powell, 1984). In soilless substrates lacking the indigenous AMF or under the conditions where field soils are fumigated and most of the indigenous AMF are eliminated, mycorrhizal inoculation is often successful and

it can increase crop uniformity and reduce transplant mortality (Vosátka et al., 1992; Vosátka, 1995). The plants grown from cuttings or small seedlings can be inoculated with pure strains of effective mycorrhizal fungi with rapid colonization rates, which allow a successful colonisation of newly formed roots after transplanting.

T. harzianum is a soil fungus exhibiting an antagonism to various fungal pathogens of the plants such as *Rhizoctonia*, *Pythium*, *Verticillium* and others. Saprophytic fungi from the genus *Trichoderma* were shown as an effective biocontrol agent in plant protection due to effective increase of plant resistance against pathogens and they were found to improve plant growth (Windham et al., 1986; Baker, 1989). The positive effects of combinations of the AMF and *T. aureoviride* were previously reported for *Tagetes erecta* grown in peat-perlite mixture (Calvet et al., 1993) and for *Citrus reshni* grown in two horticultural substrates (Camprubí et al., 1995).

The aim of this work was to evaluate the effect of inoculation of rooting substrate with arbuscular mycorhizal fungi, with *T. harzianum* or with both microorganisms together on the growth of young balcony plants *Verbena*, *Torenia* and *Diascia* propagated from cuttings.

MATERIAL AND METHODS

Herbaceous cuttings of three balcony plant species were rooted in substrate containing four volume parts of peat-perlite (3 : 1) substrate and one volume part of Vermiculite with or without inoculum (Tab. I). The experiment involved five treatments: control uninoculated plants (C), uninoculated plants treated by fungicide Previcur (P), plants inoculated with the AMF (M), plants inoculated with *T. harzianum* (T) and plants inoculated with both AMF and *Trichoderma* (MT). The AMF inoculum contained spores, mycelium and colonized root fragments of three pure AMF cultures: *Glomus fistulosum*, isolate BEG23 from the Bank of European Glomales, *G. mosseae* BEG91 and *G. intraradices* BEG93. All cultures have been maintained separately on maize grown in Vermiculite-sand mixture (5 : 1) for four months in the greenhouse. The inoculum of three AMF cultures was mixed before use. One volume part of the AMF inoculum was mixed with nine volume parts of Vermiculite for better homogenisation and this mixture was then added to peat-perlite substrate. The dose of inoculum was 0.02 litre per 1 litre of substrate. Inoculum of *T. harzianum* was applied as a product Supresivit (Fytovita, s. r. o., Praha, Czech Republic) in concentration 0.002 g per 1 litre of substrate. Supresivit was first mixed with Vermiculite and then added to the peat-perlite substrate. Previcur was applied as a 0.15% solution into the substrate after planting of unrooted cuttings.

Trays with unrooted cuttings were placed to the greenhouse with day/night temperature 20/18 °C. They were covered by PE foil for ten days and by porous foil for the next seven days. After one month cultivation without fertilizer application the rooted cuttings were transplanted into the growing substrate. The length of

I. Experimental design and treatments of the experiment with inoculation of three species of balcony plants vegetatively propagated from cuttings and inoculated with arbuscular mycorrhizal fungi and *T. harzianum*

Plants	*Verbena* Temari hybrid Pink
	Diascia elegans
	Torenia hybrid Summer Wave
Variants	C – control
	M – arbuscular mycorrhizal fungi
	T – *T. harzianum*
	MT – arbuscular mycorrhizal fungi + *T. harzianum*
	P – Previcur
No of replications	5
No of plants in each replicate	*Verbena* 20, *Torenia* 10, *Diascia* 10
Rooting	March 18, 1998
Rooting substrate	peat-Perlite substrate + Vermiculite (with or without mycorrhizal or *Trichoderma* inoculum), volume ratio 4 : 1
Trays	TEKU JP 3050/42 (42 cells, each of 71 cm^3)
Pinching	*Verbena* and *Torenia* above the second leaf couple
Transplanting	April 21, 1998
Substrate	mixture of peat, composted bark and clay (volume ratio 2 : 2 : 1) with 3 g/l of limestone, 2.5 g/l of NPK fertilizer
Trays	TEKU 3545/24 (4 cells, each of 233 cm^3)
Fertilization	3 x 0.2% nutrient solution of Kristalon Blue (20/6/19)
Evaluation of the experiment	May 19, 1998

the longest lateral shoot of *Verbena* plants was estimated on April 20, 1998 before transplanting. Fresh weight, dry weight (after oven-drying at 80 °C for 48 hours), total shoot length (*Verbena*, *Torenia*), leaf area, and number of inflorescences (only for *Verbena*) were estimated on May 19, 1998, at the end of the experiment when plants reached marketable size. *Diascia* plants were evaluated only visually according to colour of their leaves and size classes of the plants.

The root samples from ten randomly selected plants per treatment were stained with Trypan blue according to Phillips, Hayman (1970) using lactoglycerol instead of lactophenol and mycorrhizal colonization was determined by grid-line intersect method (Giovannetti, Mosse, 1980). Presence of mycelium of *T. harzianum* attached on the surface of the roots was checked visually under binocular at the magnification of 120X.

Chemical analyses (pH value and electric conductivity in water extract 1w : 5v, content of available nutrients in Ghler leaching extract) and physical analyses (bulk density) were carried out in accordance with the methods of investigation of horticultural soils and substrates.

All data sets were tested for normality and analysed by two-way analysis of variance (variants C, M, T, MT) or by one-way analysis of variance (variants C, M, T, MT, P). Significances between means were tested by Duncan's Multiple Range test ($p < 0.05$). The non-normal distributed data were transformed logarithmically. Non-parametric analysis (Kruskal-Wallis test and Connover test) of the non-normal distributed data was used.

RESULTS AND DISCUSSION

Mycorrhizal inoculation of rooting substrate positively affected growth and quality (leaf coloration) of all three tested plant species. Visual differences were apparent mainly before transplanting. Leaves of plants in both mycorrhized treatments (M, MT) were healthy green in comparison with chlorotic leaves of plant without mycorrhiza (C, T). Plants treated with Previcur (P) grew worse than in treatments M, MS but were better developed than in the treatments C, T. These differences in leaf colour were very pronounced at *Torenia* plants. Before transplanting significant effect of mycorrhizal inoculation on the growth of lateral shoots was found at *Verbena* plants (Tab. III). Relatively low level of available nutrients in the rooting substrate (Tab. II) without additional fertilisation facilitated favourable conditions for appropriate function of AMF and our findings were consistent with the results of other authors (Johnson et al., 1982; Chang, 1994). After transplanting into the growing substrate with higher available nutrient level (Tab. II) and after application of fertiliser solution the differences in leaf colour became less apparent, but growth trends were the same as in the rooting substrate. Detailed evaluation at the end of the experiment confirmed positive influence of the AMF on the plant growth. Mycorrhiza significantly increased fresh weight, dry weight, total shoot length and number of inflorescences of *Verbena* plants and dry weight and total shoot length of *Torenia* plants (Tab. III, IV, V). *Verbena* plants in-

II. Chemical and physical properties of substrates used in the experiment

Substrates	Bulk density (g/l)	pH	EC (mS/cm)	NH_4-N (mg/kg)	NO_3-N (mg/kg)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)
Rooting substrate	140	5.5	0.48	50	140	9	249	4400
Growing substrate	420	5.2	1.62	40	440	232	432	6890

III. Effect of inoculation with arbuscular mycorrhizal fungi and *T. harzianum* on the growth of *Verbena* – nondestructive analysis of plants uninoculated (C) or inoculated with arbuscular mycorrhizal fungi (M), *T. harzianum* (T) or combination of both inoculants (MT) or treated with fungicide Previcur (P); evaluations before potting on April 20, 1998 (length of the longest lateral shoot) and at the end of the experiment on May 19, 1998 (total shoot length, number of lateral shoots); results of two-way and one-way analysis of variance

Factor		Lateral shoot (cm)	Total shoot length (cm)	Number of latera shoots
Mycorrhiza	0	2.7 b[1]	80.5 b	4.5 b
	1	5.6 a	96.7 a	5.1 a
Trichoderma	0	4.2 a	90.6 a	4.8 a
	1	4.1 a	86.7 a	4.9 a
Mycorrhiza x *Trichoderma*	00 (C)	2.9 c	83.0 b	4.4 a
	10 (M)	5.5 a	98.2 a	5.2 a
	01 (T)	2.5 c	78.1 b	4.7 a
	11 (MT)	5.6 a	95.3 a	4.9 a
	00 (P)	4.1 b	84.7 b	4.4 a

[1]means followed by the same letter are not significantly different within one factor and parameter according to Duncan's Multiple Range test, $p < 0.05$

IV. Effect of inoculation with arbuscular mycorrhizal fungi and *T. harzianum* on the growth of *Verbena* – destructive analysis of plants uninoculated (C) or inoculated with arbuscular mycorrhizal fungi (M), *T. harzianum* (T) or combination of both inoculants (MT) or treated with fungicide Previcur (P); results of two-way and one-way analysis of variance

Factor		Fresh weight (g)	Dry weight (g)	Total shoot length (cm)	Leaf area (cm)	No of inflorescences	Mycorrhizal colonization (%)
Mycorrhiza	0	8.7 b[1]	2.00 b	84 b	224 a	0.08 b	0 b
	1	10.8 a	2.36 a	108 a	271 a	0.80 a	24 a
Trichoderma	0	10.1 a	2.20 a	95 a	241 a	0.53 a	22 a
	1	9.5 a	2.15 a	97 a	253 a	0.30 a	26 a
Mycorrhiza x *Trichoderma*	00 (C)	8.8 b	1.98 a	84 b	214 a	0.05 b	0 b
	10 (M)	11.3 a	2.43 a	106 a	269 a	1.00 a	25 a
	01 (T)	8.7 b	2.02 a	84 b	234 a	0.10 b	0 b
	11 (MT)	10.3 ab	2.29 a	111 a	273 a	0.60 ab	21 a
	00 (P)	8.6 b	2.02 a	89 b	233 a	0.40 ab	0 b

[1]means followed by the same letter are not significantly different within one factor and parameter according to Duncan's Multiple Range test, $p < 0.05$

V. Effect of inoculation with arbuscular mycorrhizal fungi and *T. harzianum* on the growth of *Torenia* – destructive analysis of plants uninoculated (C) or inoculated with arbuscular mycorrhizal fungi (M), *T. harzianum* (T) or combination of both inoculants (MT) or treated with fungicide Previcur (P); results of two-way and one-way analysis of variance

Factor		Shoot fresh weight (g)	Shoot dry weight (g)	Total shoot length (cm)	Mycorrhizal colonization (%)
Mycorrhiza	0	9.8 a[1]	1.13 b	102 b	0 b
	1	11.3 a	1.38 a	126 a	19 a
Trichoderma	0	10.5 a	1.20 a	117 a	21 a
	1	10.6 a	1.31 a	111 a	18 a
Mycorrhiza x *Trichoderma*	00 (C)	9.7 a	1.09 b	101 b	0 b
	10 (M)	11.2 a	1.31 ab	134 a	20 a
	01 (T)	9.9 a	1.17 b	104 b	0 b
	11 (MT)	11.3 a	1.44 a	120 ab	19 a
	00 (P)	12.2 a	1.36 ab	136 a	0 b

[1]means followed by the same letter are not significantly different within one factor and parameter according to Duncan's Multiple Range test, $p < 0.05$

oculated with the AMF were significantly better than those treated with Previcur in lateral shoot length, total shoot length and fresh weight (Tab. III, IV, V).

Application of *T. harzianum* into rooting substrate did not affect plant growth nor leaf colour in comparison with control plants (Tab. III, IV, V). Nevertheless, *T. harzianum* showed compatibility with AMF inoculation and no inhibitory effects on mycorrhizal growth response of mycorrhized plants occurred. Moreover, there was no inhibitory effect of *T. harzianum* on the development of mycorrhizal colonization by contrast to previously reported reduction of extraradical mycelium of *G. intraradices* (Green et al., 1999). Nevertheless, no inhibition of P transport via hyphae was found in that study, therefore the authors suggested that *T. harzianum* exploited only dead mycelium of the AMF. By contrast Calvet et al. (1993) found the increase of AMF colonization after preinoculation of substrate with *T. aureoviride*.

The application of Previcur as a common treatment of rooting procedure of herbaceous cuttings slightly improved leaf colour of all tested plant species. In addition length of *Verbena* lateral shoots (Tab. II) and total length of *Torenia* shoots (Tab. V) were significantly affected by Previcur treatment as well. It was possible that Previcur improved plant nutrition by suppressing substrate microorganisms competing with plants for available nutrients.

In general no negative effects of AMF inoculation has been found in any treatments what favours practical applications and confirms results of most practical tests with AMF inoculations in horticulture (Nemec, 1987). Low specificity of AMF to host plant seems to be of a great advantage, however, chemical properties, especially nutrients concentrations, of cultivation substrate can influence development and efficiency of introduced symbionts. That was indicated also by higher response of plants to AMF inoculation in early stages of cultivation in less fertile substrate. Particular care should be paid to quality and purity of inocula at its preparation since AMF cannot be grown axenically and therefore

there is a danger of inoculum contaminants, e.g. root pathogens transfer from open pot cultures commonly used for inoculum production to inoculated substrate. As suggested by Chang (1994) the combination of crop – AMF species should be also tested for particular cultivation system before large scale application.

The inoculation with AMF itself or in combination with *T. harzianum* can be a feasible biotechnology used in horticulture for better exploitation of nutrients from substrates and for improvement of growth of horticultural crops, however, careful tests for appropriate strains of AMF should be undertaken.

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KRÁTKÉ SDĚLENÍ

PUFRUJÚCA AKTIVITA NA KAMBIZEMI A PODZOLE VYVOLANÁ KYSELINOVÝM STRESOM

BUFFER ACTIVITY IN CAMBISOL AND PODZOL INDUCED BY ACID STRESS

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ABSTRACT: In the frame of pot experiment with grown plants of spring barley the influence of simulated acid load on buffer activity and some characteristics of soil absorption complex and aluminium forms in Cambisol and Podzol was observed. Two treatments were applied; treatment 1: watering by distilled water of pH 5.4, treatment 2: watering by acid solution of pH 2.5, respectively. According to theory of Ulrich (1991) pH/H_2O values indicate that Cambisol (5.23) is in the so-called silicate and Podzol (4.92) cation exchange buffer range. Simulated acid load resulted in degradation of silicate buffer system in Cambisol and cation exchange in Podzol what reflected in changes of soil absorption complex. There was found the increase of hydrolytic acidity in Cambisol from 115.3 to 159.1 mmol.kg^{-1}, in Podzol from 258 to 269.6 mmol.kg^{-1}, decrease of sum of base exchange cations in Cambisol from 176 to 160 mmol.kg^{-1}, in Podzol from 42 to 7 mmol.kg^{-1}, decrease of base saturation in Cambisol from 60.4 to 50.5%, in Podzol from 14 to 2.5% (Tabs. I, II). Effect of acid load caused increase of aluminium buffer activity in both soil representatives, the increase of labile aluminium Al^{3+} fraction from 149.7 to 397.1 mg.kg^{-1} in Cambisol and from 96.2 to 202.5 mg.kg^{-1} in Podzol. Consequently, phytotoxic aluminium effect was observed, aluminium concentration in biomass of spring barley increased from 48.5 to 110 mg.kg^{-1} in Cambisol and from 58 to 165 mg.kg^{-1} in Podzol, respectively (Figs. 1, 2). Experimentally ascertained values showed that aluminium solubility in Cambisol is controlled by composition of mineral part and in Podzol by organic matter (Tab. III, Fig. 3).

Keywords: Cambisol; Podzol; buffer activity; aluminium; acid stress; pot vegetable experiment

ABSTRAKT: Bola sledovaná pufrujúca aktivita kambizeme typickej (KMm) a podzolu typického (PZm) a zmeny chemizmu vyvolané kyselinovým stresom v podmienkach modelového nádobového vegetačného pokusu so simulovanou kyslou záťažou s dvomi variantami: 1) so zálievkou destilovanou vodou s pH 5,4 a 2) so zálievkou s pH 2,5. Podľa publikovanej teórie (Ulrich, 1991) sa KMm nachádza v pufrujúcom systéme silikátov a PZm v pufrujúcom systéme výmenných katiónov. Kyselinový stres vyvolal aktivitu a následnú degradáciu ich pufrujúcich systémov, čo sa odrazilo i v zmenách na sorpčnom komplexe. Kyselinový stres spôsobil zvýšenie hydrolytickej kyslosti u KMm o 43,8 mmol.kg^{-1}, u PZm o 11,6 mmol.kg^{-1} a pokles obsahu výmenných báz na KMm o 16 mmol.kg^{-1}, na PZm o 35 mmol.kg^{-1}. Okyslenie pôdy vyvolalo neutralizačné pôsobenie pufrujúceho systému hliníka. Jeho neutralizačné reakcie sa prejavili nárastom obsahu labilného hliníka zo 149,7 na 397,1 mg.kg^{-1} na KMm a na PZm z 96,2 na 205,5 mg.kg^{-1}. Následne bolo zistené fytotoxické pôsobenie hliníka a zvýšenie jeho obsahu v sušine jarného jačmeňa, na KMm zo 48,5 na 110 mg.kg^{-1} a na PZm z 58 na 165 mg.kg^{-1}. Experimentálne zistené hodnoty tiež ukázali, že v prípade KMm je rozpustnosť hliníka určovaná rozpustnosťou minerálneho podielu pôdy, zatiaľ čo u PZm sa uplatňujú komplexotvorné rovnováhy medzi hliníkom a pôdnou organickou hmotou.

Kľúčové slová: kambizem; podzol; pufrujúca aktivita; hliník; kyselinový stres; nádobový vegetačný pokus

ÚVOD

Akcelerácia acidifikácie pôd vplyvom kyslých atmosférických polutantov (SO_x, NO_x, NH_x) patrí k najzávažnejším ekologickým problémom súčasnosti. Spaľovanie fosílnych palív a nástup industrializácie spôsobil uvoľnenie nadmerného množstva kyslých depozít do atmosféry. Na miestach nadmerne zaťažených kyslými polutantami vzniklo vážne poškodenie životného prostredia. Interakciou znečisteného ovzdušia s pôdou došlo

k akcelerácii prirodzenej acidifikácie pôdy. Jej najnepriaznivejšími následkami sú vyplavenie živín, zvýšenie mobility a toxicity hliníka a ťažkých kovov. Pôdny ekosystém tlmí negatívne následky okyslenia systémom neutralizačných reakcií. Podľa publikovanej teórie (Ulrich, 1991) v závislosti od pH pôdy fungujú rôzne pufrujúce systémy pôdy. V rozpätí pH nad 5 je to silikátový pufrujúci systém, v rozpätí pH 4,2 až 5 systém výmenných katiónov a pri pH pod 4,2 funguje pufrujúci systém hliníka. Produktom neutralizačného pôsobenia hliníka, resp. jeho hydroxidov je labilný hliník Al^{3+}, považovaný za najnepriaznivejší následok okyslenia a rezervoár skrytej acidity pôd. Takéto a ďalšie negatívne prejavy okyslenia neustále evokujú potrebu študovať zmeny chemizmu, pufrujúcich systémov, resp. sorpčného nasýtenia pôd s kyslou či potenciálne kyslou pôdnou reakciou.

Cieľom experimentu bolo sledovať aktivitu pufrujúcich systémov, zmeny chemizmu a sorpčného nasýtenia dvoch pôdnych predstaviteľov, vyvolané simulovanou kyslou záťažou. Dôraz sme kládli na negatívne následky okyslenia, prejavujúce sa degradáciou pufrujúcich systémov, resp. ich možným posunom do oblasti pufrujúceho systému hliníka. V súvislosti s tým sme chceli poukázať aj na fytotoxické pôsobenie hliníka a výskyt jeho ďalších foriem v pôde, ako i determinovať mechanizmy kontrolujúce jeho rozpustnosť.

MATERIÁL A METÓDY

Materiálom v modelovom nádobovom vegetačnom pokuse boli dva pôdne predstavitele: kambizem typická (KMm) z katastrálneho územia Radvaň a podzol typický (PZm) z katastrálneho územia Štrbské Pleso.

Vzorky pôd boli odobraté z humusového A horizontu z piatich odberových bodov na ploche 10 m x 10 m. Zhomogenizované pôdne vzorky o hmotnosti 3 až 4 kg boli presypané do plastových prietokových nádob o objeme 4 dm^3. Pokusnou rastlinou bol jarný jačmeň, *Hordeum sativum*, odroda Favorit. Do jednej nádoby bolo vysiatych 100 zŕn v dvoch riadkoch, ktoré boli po vzídení na 11. deň vyjednotené na 20 jedincov. Boli zvolené dva varianty: 1. pôda, jarný jačmeň, zálievka (destilovaná voda s pH 5,4); 2. pôda, jarný jačmeň, zálievka (kyslý roztok s pH 2,5).

Zálievka bola aplikovaná trikrát týždenne po 200 ml (vypočítané z ročného úhrnu zrážok 600 mm). Kyslý roztok s pH 2,5 bol použitý na simuláciu kyslých zrážok. Bol pripravený ako zmes destilovanej vody, kyseliny sírovej a kyseliny dusičnej. V prepočte tri mesiace zalievania roztokom s pH 2,5 sa vyrovnajú (kyslou záťažou) zrážkam s pH 4,4 počas 19 rokov (vypočítané podľa váženého priemeru zrážok na území SR za rok 1989, Mitošinková, 1993). Vegetačný pokus trval 88 dní. Prvý odber bol uskutočnený na 38., druhý na 63. a tretí na 88. deň pokusu. Pôdne vzorky boli vysušené na vzduchu, zhomogenizované, preosiate cez sito s priemerom ôk 2 mm. Vo vzorkách bola stanovená hydrolytická kyslosť titračne pôsobením hydrolyticky zásaditej soli, obsah výmenných báz Kappen-Gilkovicovou metódou, pH/H_2O, aktívny hliník podľa Sokolova, organicky viazaný hliník v 0,1M $Na_4P_2O_7$, aktivita Al^{3+} v 0,01M $CaCl_2$ pri pomere zemina : roztok 1 : 5, obsah hliníka v rastline metódou AAS, ílové minerály röntgenodifraktometrickou analýzou za podmienok: 35kV-20mA, 2°-0,2°-2°, 1000/4, Cu-K, Ni filter. Testy: sýtenie Mg^{2+}, sýtenie Mg^{2+} + solvatovanie etylénglykolom, žíhanie pri 550 °C.

VÝSLEDKY A DISKUSIA

V podmienkach modelového vegetačného pokusu sme pozorovali zmeny chemizmu vyvolané kyselinovým stresom na KMm využívanej ako pasienok a na PZm využívanom ako lesná pôda. Vychádzajúc z pôvodných parametrov, hodnotami pH/H_2O sa KMm (5,23) podľa

I. Zmeny obsahu výmenných báz (*S*), hydrolytickej kyslosti (*H*), sorpčnej kapacity (*T*-KVK) a stupňa sorpčnej nasýtenosti (*V*) na kambizemi typickej – Sum of base cations (*S*), hydrolytic acidity (*H*), cation exchange capacity (*T*-CEC) and base saturation (*V*) changes in Cambisol

Variant[1]	Odber[2]	*S*		*H*		*T*	*V*
		priemer[3] ($mmol.kg^{-1}$)	rozpätie[4] (%)	priemer ($mmol.kg^{-1}$)	rozpätie (%)	priemer ($mmol.kg^{-1}$)	priemer (%)
1	0	176	–	115,3	–	291,3	60,4
	I	176	6,8	138,7	22,3	314,7	55,9
	II	187	1,6	121,6	0,6	308,1	60,5
	III	182	0	118,8	5,7	300,8	60,5
2	0	176	–	115,3	–	291,3	60,4
	I	177	1,1	137,2	3,4	314,2	56,3
	II	174	2,3	144,3	0,8	318,3	54,7
	III	160	2,5	159,1	2,5	319,1	50,5

Vysvetlivky k tab. I a II – Explanations to Tabs. I and II:
variant 1: zálievka, destilovaná voda – treatment 1: watering, distilled water
variant 2: zálievka, roztok s pH 2,5 – treatment 2: watering, solution of pH 2.5

[1]treatment, [2]sampling, [3]average, [4]range

teórie (Ulrich, 1991) nachádza v pufrujúcom systéme silikátov a PZm (4,92) v pufrujúcom systéme výmenných katiónov. Sorpčný komplex KMm, tvorený asociáciou ílových minerálov smektit >> illit > kaolinit, bol slabo nasýtený (60,42 %) a u PZm, tvorený asociáciou ílových minerálov chlorit >> illit >> smektit, bol extrémne nenasýtený (14,0 %). Vzhľadom na nízke nasýtenie sorpčného komplexu na PZm predpokladáme, že prítomné smektity, vyznačujúce sa dobrými sorpčnými vlastnosťami – vysokou sorpčnou kapacitou a napučiavaním, charakteristické svojím výskytom v produkčných pôdach, sú tu zastúpené beidelitmi – zo skupiny Al smektitov. Hodnota hydrolytickej kyslosti na KMm bola 115,29 mmol.kg^{-1} a na PZm 258,02 mmol.kg^{-1}.

V priebehu pokusu došlo vplyvom kyselinového stresu k zmenám zastúpenia výmenných katiónov sorpčného komplexu (tab. I, II). Dôsledkom narastajúceho vstupu protónov do pôdy sa zvýšili hodnoty hydrolytickej kyslosti u oboch pôdnych predstaviteľov na oboch variantoch, výraznejšie na variante 2 s kyslou zálievkou. Pôvodná hodnota hydrolytickej kyslosti sa na KMm zvýšila na variante 1 (s destilovanou vodou) o 3,5 mmol.kg^{-1} a na variante 2 o 43,8 mmol.kg^{-1}. Na PZm hydrolytická kyslosť klesla na variante 1 o 39,5 mmol.kg^{-1} a na variante 2 narástla o 11,6 mmol.kg^{-1} (tab. I, II). Obsah výmenných báz sa u KMm na variante 1 zvýšil o 6 mmol.kg^{-1} a na variante 2 klesol o 16 mmol.kg^{-1}. Na PZm obsah výmenných báz klesol na oboch variantoch, na variante 1 o 32 mmol.kg^{-1}, na variante 2 o 35 mmol.kg^{-1}. Vplyvom kyslej zálievky sa nasýtenosť sorpčného komplexu znížila na KMm z 60,4 na 50,5 % a na PZm zo 14 na 2,5 %.

F-test hodnôt obsahu výmenných báz (S) a hydrolytickej kyslosti (H) ukázal, že na 5% hladine významnosti sa vplyv kyslej zálievky štatisticky významne prejavil najmä v prípade PZm (tab. III).

Hodnoty pH/H_2O na variante s kyslou zálievkou klesli na KMm z 5,23 na 4,40 a na PZm z 4,92 na 4,31. Pôdne ekosystémy sa posunuli do nižších pufrujúcich systémov. KMm do pufrujúceho systému výmenných katiónov a PZm sa výrazne priblížil pufrujúcemu systému hliníka. Reakcie dominantných pufrujúcich systémov v určitom rozpätí pH neprebiehajú izolovane, ale sú sprevádzané akcesorickými neutralizačnými reakciami. Okysľovanie pôdy, resp. znižovanie pH indikuje neutralizačné pôsobenie hliníka. Jeho pufrujúca aktivita rastie v kyslých pôdach s pH < 5,5 a dosahuje maximum pri pH < 4,2, naopak v rozhraní pH 5 až 7 je najmenej rozpustný (Susser, Schwertmann, 1991). Poklesom pH vyvolaným kyselinovým stresom v priebehu pokusu sa zvýšila neutralizačná aktivita hliníka. Prejavila sa nárastom obsahu labilného Al^{3+} v pôde. Na KMm bol nameraný nárast labilného Al^{3+} na variante 2 (s kyslou zálievkou) zo 149,7 na 397,1 mg.kg^{-1}, na PZm z 96,2 na 202,5 mg.kg^{-1} (obr. 1, 2).

Toxický vplyv labilných iónov hliníka sa prejavil limitovaním rastu jarného jačmeňa a jeho predčasným ukončením vo fáze steblovania. Zároveň bola zistená vysoká koncentrácia hliníka v sušine rastlín. Obsah hliníka vplyvom kyslej zálievky na variante 2 narástol

II. Zmeny obsahu výmenných báz (*S*), hydrolytickej kyslosti (*H*), sorpčnej kapacity (*T*-KVK) a stupňa sorpčnej nasýtenosti (*V*) na podzole typickom – Sum of base cations (*S*), hydrolytic acidity (*H*), cation exchange capacity (*T*-CEC) and base saturation (*V*) changes in Podzol

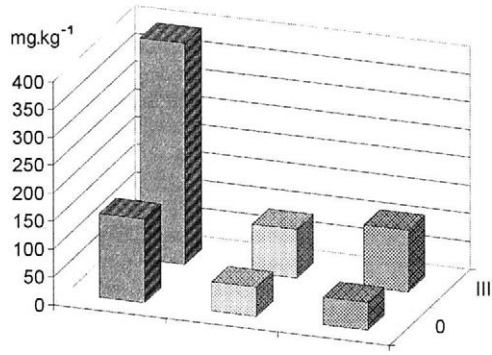
Variant[1]	Odber[2]	*S*		*H*		*T*	*V*
		priemer[3] (mmol.kg^{-1})	rozpätie[4] (%)	priemer (mmol.kg^{-1})	rozpätie (%)	priemer (mmol.kg^{-1})	priemer (%)
1	0	42	–	258,0	–	300,0	14,0
	I	40	10	265,2	0,2	305,2	13,1
	II	29	22	196,5	4,7	225,5	12,9
	III	10	30	218,5	20,5	228,5	4,4
2	0	42	–	258,0	–	300,0	14,0
	I	46	20	258,8	7,9	304,8	15,1
	II	35	25	247,2	1,7	282,2	12,4
	III	7	32	269,6	8,2	276,6	2,5

For 1–4 see Tab. I

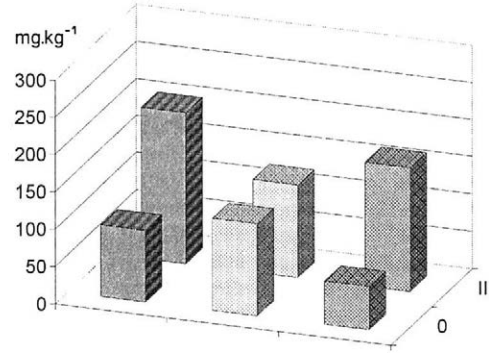
III. Analýza variancie hodnôt obsahu výmenných báz (*S*) a hydrolytickej kyslosti (*H*) podľa aplikovanej kyslej zálievky – Analysis of variance of values of sum of base cations (*S*) and hydrolytic acidity (*H*) according to applied acid watering

Pôdna jednotka[1]	Stupne voľnosti[2]	*S*			*H*		
		priemerný štvorec[3]	*F*-test[4]	hladina významnosti[5]	priemerný štvorec	*F*-test	hladina významnosti
Kambizem typická[6]	1	24,69	0,30	0,6435	12,03	0,02	0,8900
Podzol typický[7]	1	887,62	42,89^{++}	0,0225	10 025,10	88,67^{++}	0,0111

[1]soil unit, [2]*d.f.*, [3]mean square, [4]*F*-ratio, [5]*P*-value, [6]Cambisol, [7]Podzol



1. Zmeny foriem hliníka na kambizemi typickej na variante 2 – Aluminium forms changes in Cambisol in treatment 2



2. Zmeny foriem hliníka na podzole typickom na variante 2 – Aluminium forms changes in Podzol in treatment 2

▨ aktívny – labile
▨ organický (.100) – organic (.100)
▨ rastlinný – plant
0–III = odber – sampling

v sušine jarného jačmeňa na PZm z 58 $mg.kg^{-1}$ pri prvom odbere na 165 $mg.kg^{-1}$ na konci pokusu a na KMm zo 48,5 $mg.kg^{-1}$ pri prvom odbere na 110 $mg.kg^{-1}$ na konci pokusu (obr. 1, 2).

Uvedené čísla poukazujú na ekologické nebezpečenstvo labilného hliníka, čo vyžaduje nielen hlbšie skúmanie jeho toxických foriem, ale aj jeho zdrojov. Za základný zdroj hliníka v pôde sa v literatúre považuje rozpúšťanie primárnych a sekundárnych minerálov (Bertsch, 1989; Bache, 1991; Ritchie, 1995). Pri pH > 4,1 je rozpustnosť hliníka kontrolovaná hydroxidom hlinitým, ale v kyslých, na organickú hmotu bohatých pôdach sa do kontroly rozpustnosti zapája i organická hmota (Wesselink et al., 1996), čo sme overovali aj v našom pokuse.

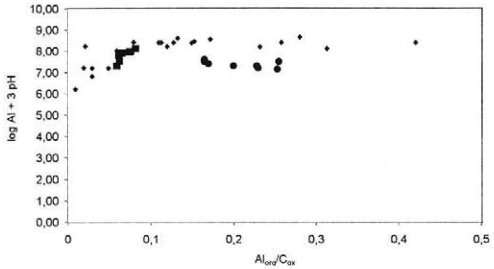
Množstvo nameraného organicky viazaného hliníka, extrahovaného 0,1M $Na_4P_2O_7$, bolo vyššie v lesnej pôde (PZm, 13 500 $mg.kg^{-1}$) ako v pôde pod trvalým trávnym porastom (KMm, 5 250 $mg.kg^{-1}$). V priebehu pokusu sa obsah organického hliníka na PZm na variante 1 (s destilovanou vodou) znížil. Na variante 2 (s kyslou zálievkou) mal kolísavý priebeh, ale jeho výsledná koncentrácia bola zhodná s východiskovým obsahom na začiatku pokusu. Na KMm došlo na oboch variantoch k jeho zvýšeniu, výraznejšie na variante 2 s kyslou zálievkou.

Na rozdiel od obsahu aktívneho hliníka nebol v zhode s publikovaným tvrdením (Kozák, Borůvka, 1998) obsah organicky viazaného hliníka jednoznačne ovplyvnený pôdnou reakciou (tab. III). Na KMm došlo s poklesom pH k nárastu organicky viazaného hliníka, na PZm sa naopak jeho obsah s poklesom pH znižoval.

IV. Analytické výsledky použité pri štúdiu organicky viazaného hliníka – Analytical results used for the study of organically bound aluminium

	Variant[1]	Odber[2]	pH/$CaCl_2$	C_{ox} (%)	Al/$Na_4P_2O_7$ ($mg.kg^{-1}$)	log Al_{akt}	Al($Na_4P_2O_7$)/C_{ox} ($mol.mol^{-1}$)	log Al + 3 pH
Kambizem typická[3]	1	0	4,18	1,5	5 250	–5,05	0,16	7,50
		I	4,09	1,3	5 000	–4,86	0,17	7,41
		II	4,09	1,3	6 300	–4,97	0,22	7,29
		III	4,13	1,3	7 300	–4,86	0,25	7,52
	2	0	4,18	1,5	5 250	–5,05	0,16	7,50
		I	4,01	1,4	6 050	–4,68	0,19	7,36
		II	3,97	1,5	7 400	–4,64	0,23	7,27
		III	3,90	1,5	8 650	–4,44	0,25	7,26
Podzol typický[4]	1	0	4,07	6,2	12 350	–4,12	0,09	8,09
		II	4,02	6,6	11 150	–4,10	0,07	7,96
		III	4,04	6,5	11 150	–4,15	0,08	7,97
	2	0	4,07	6,2	12 350	–4,12	0,09	8,09
		I	3,99	8,4	12 100	–4,04	0,06	7,93
		II	3,80	8,3	11 500	–3,85	0,06	7,55
		III	3,66	9,6	12 350	–3,73	0,06	7,25

[1]treatment, [2]sampling, [3]Cambisol, [4]Podzol



3. Experimentálne zistené hodnoty (log Al + 3 pH) ako funkcia molárneho pomeru Al_{org}/C_{ox} – The experimentally ascertained values (log Al + 3 pH) as function of molar ratio Al_{org}/C_{ox}

◆ kambizeme dystrické – Dystric Cambisols (Dlappa et al., 1997)
■ podzol typický – Podzol
● kambizem typická – Cambisol

Pre sledovanie kontroly rozpustnosti boli použité experimentálne zistené hodnoty (log Al + 3 pH) namerané vo výluhu 0,01M $CaCl_2$ a vynesené do grafu ako funkcia molárneho pomeru hliníka extrahovateľného difosforečnanom tetrasodným (Al_{org}) k obsahu oxidovateľného uhlíka (C_{ox}) (tab. IV, obr. 3).

Z usporiadania nameraných hodnôt u KMm a PZm voči hodnotám, ktoré zistili Dlapa et al., (1997), je zrejmé, že hliník na PZm vykazuje podobné správanie ako lesné kambizeme dystrické.

Pri hodnotách pomeru $Al_{org}/C_{ox} > 0,1$ je rozpustnosť kontrolovaná hydroxidom hlinitým a hodnota (log Al + 3 pH) je konštantná, na PZm preto hodnoty $Al_{org}/C_{ox} <$ 0,1 (0,06 až 0,09) korelujúce s hodnotami pomeru (log Al + 3 pH) prekročili pufračnú bariéru hydroxidov hliníka a posunuli sa do oblasti, kde je rozpustnosť hliníka určovaná komplexotvornými reakciami medzi hliníkom a pôdnou organickou hmotou.

U KMm bola situácia odlišná. Interakčné body medzi Al_{org}/C_{ox} a (log Al + 3 pH) ležia pod myslenou krivkou vyznačených bodov na obr. 3, čo indikuje, že u nej nekontrolujú rozpustnosť ani hydroxidy hliníka, ani organická hmota, ale iná minerálna substancia.

ZÁVER

Zmeny chemizmu vyvolané simulovanou kyslou záťažou, demonštrované na príklade dvoch vybratých pôdnych predstaviteľov KMm a PZm, poukazujú na vážne riziká spojené s antropogénnou akceleráciou acidifikácie pôdy. Pufrujúce systémy KMm a PZm degradovali vplyvom kyselinového stresu, KMm zo silikátového do pufrujúceho systému výmenných katiónov a PZm z oblasti výmenných katiónov k oblasti hliníka. Neutralizačné pôsobenie hliníka sa negatívne odrazilo nárastom obsahu labilného Al^{3+} v pôde, jeho fytotoxickým pôsobením a nárastom obsahu hliníka v sušine jarného jačmeňa. Experimentálne získané výsledky potvrdili, že na PZm sa do kontroly rozpustnosti významne zapája organická hmota.

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Volume 46, No. 3 March 2000

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