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CHANGES IN GRASSLAND CHEMICAL SOIL PARAMETERS FOUR YEARS AFTER CESSATION OF DIFFERENT FERTILISATION WITH COMPOST AND SLURRY

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Abstract

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The aim of this study was to evaluate changes in chemical soil properties of permanent grasslands after the cessation of their regular utilisation and organic fertilisation. A long-term small plot trial was established in 2004 in locality Rapotín. During 2004–2012 the experiment was fertilised with compost and slurry, both with the range of stocking rates 0.9, 1.4, and 2.0 livestock units (LU).ha^{-1} (corresponding to 54, 84, and 120 kg N.ha^{-1}). It was further observed the unfertilised grassland as control. The plots were cut 2–4 times per year depending on given dose of fertiliser. During 2013–2016 the regular management was ceased and the grasslands were completely abandoned. It was found statistically significant influence of the year and the type of fertiliser almost for all evaluated parameters. The dose of nitrogen was not significant. On the basis of our results we can conclude, that the both types of the organic fertilisers had a positive influence on the chemical soil properties, however, the compost manifested itself as the better fertiliser than the slurry from this point of view. In 2016, four years after the last application of the organic fertilisers, there were found the better chemical soil conditions in the treatments previously fertilised with compost.

Keywords: grassland; organic fertilisers; soil; abandonment

INTRODUCTION

For the support of the growth, the development and the proper quality of the fodder crops it is essential their adequate nutrition. In most of the enterprises that are engaged in plant and animal production it is usual to fertilise grasslands with mineral fertilisers. Therefore, many authors were aimed at the investigation of the influence of mineral fertilisation on the floristic composition of grasslands (e.g. Mrkvička and Veselá, 2002; Hejcman *et al.*, 2007; Smits *et al.*, 2008; Britaňák *et al.*, 2009; Hrevušová *et al.*, 2009; Rotar *et al.*, 2016). The systematic utilisation of farm manures in grasslands is not common because of their preferred application in the intensive crop management on arable land. Existing methodical recommendations for the utilisation of organic fertilisers often do not take into consideration many important criterions, such as the estimation of the type and the dose of fertiliser in relation to the type of grassland, the altitude, or the date of application. Long-time experience is used in alpine regions (Buchgraber *et al.*, 2011).

The organic fertilisers are the irreplaceable base for the rational agriculture. The high-quality farm manures support the soil fertility and have other positive effects (Samuil *et al.*, 2009). By their correct systematic application, the important nutrients are returned back to the soil and the additional fertilisation with mineral fertilisers is not generally necessary in grasslands. The difference is, that the nutrients in inorganic fertilisers can be directly taken up by plants in contrast to nutrients in organic fertilisers, which have to be released by microbial metabolism to make most of them available to plants (Böhme *et al.*, 2005).

There is an advantage of organic fertilisers which lays in the fact, that their application can positively influence the soil organic carbon content (Gonet and Debska, 2006). Microorganisms, e.g. bacteria, fungi, actinomycetes and microalgae, play a key role in organic matter decomposition, nutrient cycling and other chemical transformations in soil (Murphy *et al.*, 2007; Chang *et al.*, 2014). The results of Šimon and Czakó (2014) indicated that additions of organic matter from various sources differ in the effects on soil organic matter and biological activity. According these authors, long-term application of cattle slurry + straw was rather similar to mineral fertilisation. Hlisnikovský *et al.* (2016) came to the conclusion, that the decomposition and subsequent stabilization of fresh organic matter in time, the microbial interactions and mineralization of soil organic matter (Gude *et al.*, 2012) and changes of contents of organic carbon were probable reasons for the subsequent decrease of easily available carbon fractions and increase of available metals in their experiment. It follows that, there should be a long-term residual effect of organic fertilisers' application (Diacono and Montemurro, 2010) which was, however, only rarely investigated in grasslands.

Another question, which has been frequently asked by scientists (e.g. Bohner *et al.*, 2006; Prévosto *et al.*, 2011; Pavlů *et al.*, 2013; Ronch *et al.*, 2013; Plesa *et al.*, 2014), is addressed to changes after the total grassland abandonment. The abandonment of semi-natural grasslands become a major threat and raises a series of questions and situations, which have to be solved in the whole Europe (Osterburg *et al.*, 2010). This topic is still actual, because the grassland abandonment is happening currently mainly in the less-favoured areas near the borders of the Czech Republic.

The influence of organic fertilisers (cattle slurry, in particular) has been studied e.g. Estavillo *et al.* (1997), Schellberg and Lock (2009), Liu *et al.* (2010), Lalor *et al.* (2011, 2012), Duffková *et al.* (2015), Angeringer *et al.* (2016). As Khalid *et al.* (2013) documented, compost works quite differently from mineral fertilisers, as amending soil with compost provides a slow-release source of nutrients. Significant quantities of nutrients (particularly N, P, K and micronutrients) became bio-available with time as compost decomposed in the soil. In addition, if sufficient heat is generated the viability of weed seeds in the material should be reduced (Younie, 2012). On the contrary, slurry is the fertiliser with a quick-release nitrogen because the ratio C:N < 10 (Decree no. 474/2000 Coll.).

Our study is based on the long-term investigation of the small-plot trial with permanent grassland and it broadens the current knowledge about these topics. The aim of this work was to verify the influence of organic fertilisers on chemical properties of the soil, to compare the effects of fertilisation with slurry and compost, to assess the use of compost for fertilisation of grasslands.

MATERIALS AND METHODS

Study site

The monitoring of the influence of intensity of utilisation and type and level of grassland fertilisation with organic fertilisers was initiated in Rapotín in 2004. The experimental site was situated in the Czech Republic (50°00¢32²N and 17°00¢83²E) at 390 m above sea level on the east slope position (declination between 5.1 and 6.2°) in a moderately warm region without temperature extremes (Quitt, 1971). Average annual temperature is 7.2 °C and annual precipitation 693 mm. Further meteorological data are given in Tab. I. The vegetation of the experimental area was classified as *Cynosurion* with some elements of *Arrhenatherion* (Moravec *et al.*, 1995). Before the experiment set-up, the grassland was utilised as the pasture for cattle. The soil was sandy-loam, *Haplic Cambisol* with horizons Am-Bv-Bv/Cc-Cc (classification system according to IUSS Working Group WRB 2006). The chemical soil properties were determined in spring 2012 and 2016 according to the methods of Zbíral *et al.* (2002).

Treatments

A long-term small-plot experiment (plot size: 12.5 m^2) in completely randomised blocks with four replicates was investigated on permanent grassland. Two types of organic fertilisers were applied during 2004–2012: (S) cattle slurry, and (C) compost. Organic fertilisers were used in annual doses of nitrogen: 54 $kg.ha^{-1}$, 84 $kg.ha^{-1}$ and

I: *Long-term annual average [1961–1990] in temperatures and precipitations in the locality of Rapotín*

	Normal
Average temperature during the vegetation season [°C]	9.1
Average annual temperature [°C]	7.2
Average precipitation during the vegetation season [mm]	481
Average annual precipitation [mm]	693

120 kg.ha^{-1}, which approximately corresponded to 0.9 LU.ha^{-1} (LU = livestock unit), 1.4 LU.ha^{-1} and 2.0 LU.ha^{-1}. The fertilisers were analysed for the content of nutrients before their application, which was conducted annually during 2004–2012. Average concentration of nitrogen in organic fertilisers was 3.6% (in dry matter) for slurry and 1.3 % (in dry matter) for compost. Average concentrations of other elements in the organic fertilisers are mentioned in Tab. II. The first half of the doses of the cattle slurry (diluted with water in a ratio 1:3) as well as the compost was applied early in spring and the second one after the first cut. The plots were cut two to four times per year depending on the given dose of fertiliser. Treatments of the fertilisation and the cutting regime are given in Tab. III.

During 2013–2016, the regular management was ceased and the grasslands were completely abandoned for this time.

Evaluated parameters

The soil chemical properties were evaluated in two laboratories. The accredited laboratory of Agrovyzkum Rapotin Ltd. determined 1) the content of total organic carbon (C_{ox}) using spectrophotometry according to Zbíral *et al.* (2004), 2) the content of basic macronutrients (Mg, Ca, P, K) in the Mehlich-3 Extractant (Mehlich, 1984), 3) the exchangeable soil reaction (pH 1M $CaCl_2$), and 4) the content of total Kjeldahl nitrogen (N_{tot}) by means of the Kjeldahl method.

The laboratory of Research Institute for Soil and Water Conservation (In Czech VÚMOP, v.v.i.) determined the fractional composition of humus substances: HA – humic acids and FA – fulvic acids by means of the method of short fractionation according to Konová and Bělčíková (1963).

Statistical analyses

Analysis of variance (ANOVA) followed by Tukey HSD test ($P < 0.05$), and further the T-test ($P < 0.05$), were used for the statistical data analysis by means of the software Statistica v. 10.

RESULTS AND DISCUSSION

Chemical parameters of soil determined in spring 2011 and 2016 are shown in Tab. IV.

Tab. V shows the statistically significant differences in particular characteristics between years 2011 and 2016.

Concerning the exchangeable soil reaction, it was found statistically significant ($P < 0.05$) influence of the year and of the type of fertiliser. The factor „dose of nitrogen“ was not significant. From Tab. IV it is obvious, that in 2016, the pH value was significantly higher than in 2011 (5.20 and 4.92, respectively). Further, it was found, that the fertilisation with compost increased the soil reaction. On average,

II: *Average concentrations of elements in organic fertilisers (in dry matter)*

Fertiliser	P	K	Ca	Mg	Cd	Zn	Co	Cu	C*
	(mg.kg^{-1})								(%)
Slurry	6,611	26,284	11,770	24,928	0.142	329	4.2	29	35
Compost	4,239	22,331	20,584	76,274	0.012	273	3.9	35	52

*C - total content of carbon determined by loss ignition method

III: *Description of treatments with different grassland management (before abandonment)*

Treatment	Fertilisation	Annual dose of nitrogen	Application	1st cut	2nd cut	3rd cut	4th cut
S-0.9	cattle slurry (diluted with water 1:3)	54 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	June 15	Sept. 30	-	-
S-1.4	cattle slurry (diluted with water 1:3)	84 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	May 30	July 30	Sept. 30	-
S-2.0	cattle slurry (diluted with water 1:3)	120 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	May 15	June 30	Aug. 15	Sept. 15
C-0.9	compost	54 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	June 15	Sept. 30	-	-
C-1.4	compost	84 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	May 30	July 30	Sept. 30	-
C-2.0	compost	120 kg.ha^{-1}	50% of dose - in spring, 50% of dose - after the 1st cut	May 15	June 30	Aug. 15	Sept. 15

the highest pH value showed the compost treatments (5.25) compared to the slurry treatments (4.97) and the controls without fertilisation (4.78). The long-term organic fertilisers application can lead to the decrease of soil reaction as mentioned e.g. Meng *et al.* (2005) or Bastida *et al.* (2008), however the compost has got the puffer ability and it can soften the soil acidity (Florián, 2014), as it was proved also by our results. Higher pH is important in view of reality that under acidic, waterlogged conditions, high organic matter can further increase potential toxicity (Carrow *et al.*, 2001).

Further, it was found statistically significant influence of the year and of the type of fertiliser for the content of N_{tot}. In 2016, the content of N_{tot} was significantly higher than in 2011 (0.21% and 0.19% respectively). On average, the highest content of N_{tot} showed the compost treatments (0.21%) compared to the slurry treatments (0.19%) and the controls without fertilisation (0.17%). Many authors referred, that any type of organic fertiliser increased

IV: *Chemical parameters of soil determined in spring 2011 and 2016*

Year	Treatment	pH	C_{ox}	N_{tot}	Ratio	HA	FA	Ratio	P	K	Ca	Mg
		($CaCl_2$)	(%)	(%)	C/N	(%)	(%)	HA/FA	(mg. kg^{-1})	(mg. kg^{-1})	(mg. kg^{-1})	(mg. kg^{-1})
2011	Control	4.75	1.46	0.18	8.08	0.26	0.46	0.58	53	159	1,944	173
2011	S-0.9	4.83	1.59	0.19	8.53	0.30	0.36	0.84	59	161	2,078	209
2011	S-1.4	4.70	1.44	0.17	8.51	0.26	0.35	0.74	55	155	1,954	185
2011	S-2.0	4.78	1.41	0.17	8.16	0.28	0.45	0.62	48	162	1,855	195
2011	C-0.9	5.13	1.58	0.20	8.11	0.34	0.45	0.75	74	196	2,399	228
2011	C-1.4	5.07	1.61	0.19	8.43	0.34	0.43	0.80	70	151	2,383	216
2011	C-2.0	5.21	1.74	0.20	8.56	0.34	0.50	0.68	92	180	2,493	260
2016	Control	4.81	0.70	0.16	4.40	0.24	0.37	0.66	50	142	1,660	197
2016	S-0.9	5.16	0.88	0.20	4.33	0.32	0.39	0.80	46	150	2,118	269
2016	S-1.4	5.18	0.85	0.20	4.21	0.33	0.38	0.85	61	124	2,125	291
2016	S-2.0	5.17	0.93	0.19	4.86	0.30	0.38	0.79	57	107	2,107	296
2016	C-0.9	5.43	1.20	0.24	5.05	0.49	0.42	1.16	75	138	1,760	279
2016	C-1.4	5.12	1.13	0.22	5.15	0.40	0.39	1.02	64	114	2,823	321
2016	C-2.0	5.52	1.17	0.22	5.19	0.48	0.41	1.16	93	127	2,742	323
Means - Year												
2011		4.92^{a}	1.55^{a}	0.19^{a}	8.34^{a}	0.30^{a}	0.43^{a}	0.72^{a}	65	166^{a}	2,158	209^{a}
2016		5.20^{b}	0.98^{b}	0.21^{b}	4.74^{b}	0.36^{b}	0.39^{b}	0.92^{b}	64	129^{b}	2,191	282^{b}
Means - Fertiliser												
Nil-fertilisation		4.78^{a}	1.08^{a}	0.17^{a}	6.24^{a}	0.25^{a}	0.41^{ab}	0.62^{a}	51^{a}	150	$1,802^{a}$	185^{a}
Slurry		4.97^{a}	1.18^{a}	0.19^{b}	6.43^{ab}	0.30^{a}	0.39^{a}	0.77^{b}	54^{a}	143	$2,039^{a}$	241^{b}
Compost		5.25^{b}	1.41^{b}	0.21^{c}	6.75^{b}	0.40^{b}	0.43^{b}	0.93^{c}	78^{b}	151	$2,433^{b}$	271^{c}
Means - Dose of nitrogen												
0 kg.ha^{-1}		4.78	1.08	0.17	6.24	0.25	0.41^{ab}	0.62	51	150	1,802	185^{a}
54 kg.ha^{-1}		5.14	1.31	0.21	6.50	0.36	0.40^{ab}	0.89	63	161	2,089	246^{b}
84 kg.ha^{-1}		5.02	1.26	0.20	6.57	0.33	0.39^{a}	0.85	62	136	2,321	253^{b}
120 kg.ha^{-1}		5.17	1.31	0.20	6.69	0.35	0.43^{b}	0.81	73	144	2,299	268^{b}
Factor							*P*-value					
Year		<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.843	<0.001	0.752	<0.001
Fertiliser		<0.001	<0.001	<0.001	0.029	<0.001	<0.001	<0.001	<0.001	0.333	0.001	<0.001
Dose of nitrogen		0.214	0.401	0.230	0.545	0.380	0.006	0.287	0.245	0.054	0.179	0.048

Legend: S = slurry; C = compost; 0.9; 1.4; 2.0 = model stocking rate (LU.ha^{-1});
C_{ox} = total organic carbon; N_{tot} = total Kjeldahl nitrogen; HA = humic acids; FA = fulvic acids
(Soil quality parameters were determined according to the methods of Zbíral *et al.* 2002.)
The values in the same column with different superscript letters are significantly different at $P < 0.05$ level for each variable (Tukey's HSD test).

V: *T-test results between years 2011 and 2016*

	pH	C_{ox}	N_{tot}	C/N	HA	FA	HA/FA	P	K	Ca	Mg
2011	0.008692	0.227240	0.077296	0.905861	0.036986	0.016741	0.811673	0.124035	0.280041	0.038000	0.102346
2016	0.274034	0.007132	0.029316	0.064497	0.048785	0.092827	0.044450	0.152554	0.978939	0.441710	0.069472

the content of N_{tot} in the soil (Blackshaw *et al.*, 2005; Leroy *et al.*, 2007). In our case, there was found the statistically significant difference ($P < 0.05$) in the content of N_{tot} in the treatments fertilised with compost and slurry, whereas the content of N_{tot} was significantly higher in the compost treatments. This finding is in agreement with Whalen and Chang (2002), who mentioned that compost is better organic fertiliser, because the important nutrients are available in the soil in a higher amount and in a longer period. According to Younie (2012) converts much of the N to more stable forms of organic N which are less susceptible to loss during and after application in the field. However, considerable volatilization losses of N will occur during the composting process itself. Further, Diacono and Montemurro (2010) mentioned, that repeated long-term applications of organic amendments not only generally increase the size of the soil organic N pool, but also cause remarkable changes in soil characteristics, that influence N dynamics and can lead to a residual effect. Habteselassie *et al.* (2006) found an 89% increase in total soil N content after 5 years when dairy-waste compost at 200 kg.ha^{-1} N was applied. The increase in total soil N content was found also in our study four years after the last fertilisers' application, which was the most apparent in the treatments fertilised with compost.

As for the content of C_{ox}, (which represents the primary soil organic matter), also in this case it was found statistically significant ($P < 0.05$) influence of the year and of the type of fertiliser. In 2016, the content of C_{ox} was significantly lower than in 2011 (0.98% and 1.55%, respectively). On average, the highest content of C_{ox} showed the compost treatments (1.41%) compared to the slurry treatments (1.18%) and the controls without fertilisation (1.08%). Montemurro *et al.* (2006) documented, that the compost is the better source of the organic matter, which is more stable in a long-term. It was observed also in our study.

Within our study, we evaluated the humus quality, whereas the basic indicator of the quality of humus is the ratio C/N. Generally, the narrower value than 10 means the better humus quality and vice versa (Fiala and Krhovjáková, 2009). We have found, that the value of this ration was below 10 in all treatments, however, in 2016, the ratio C/N was significantly narrower than in 2011 (4.74 and 8.34, respectively). On average, the compost treatments (6.75) differed significantly ($P < 0.05$) from the controls (6.24).

The humus quality was further estimated by means of the contents of humic acids and fulvic acids. The wider ratio HA/FA means the dominance of humic acids and the higher humus quality and vice versa (Bensa *et al.*, 2015). It means also the higher degree of humification. The values of ratio HA/FA between 0.5–1.0 means the degree of humification between 20–30%. The values of ratio HA/FA between 1.0–2.0 means the degree of humification between 30–40%. We have found statistically significant ($P < 0.05$) influence of the year and of the type of fertiliser, whereas in 2016, the ratio HA/FA was significantly wider than in 2011. On average, the compost treatments (0.93) differed significantly ($P < 0.05$) from the slurry treatments (0.77) and from the controls without fertilisation (0.62). The widest ratio HA/FA was found in the compost treatments in 2016, whereas the ratio exceeded the value 1 for all treatment of doses of nitrogen.

Finally, we evaluated the differences between treatments in the content of basic macronutrients. From Tab. IV it is apparent, that there were found differences within treatments and years and some of them were significant ($P < 0.05$). It was found statistically significant difference ($P < 0.05$) between the years 2011 and 2016 in the content of K and Mg. Significant difference between the types of fertiliser was found for all macronutrients (except potassium), whereas the highest content of macronutrients showed the compost treatments. Concerning the potassium, it was found also the significant influence of the year, whereas the higher content of K was found in 2011 (166 mg.kg^{-1}) compared to 2016 (129 mg.kg^{-1}). The most significant differences were found for the magnesium, whereas the significant was the factor „type of the fertiliser" as well as its „dose". As it is apparent in Tab. IV, the highest content of Mg was found for the highest dose of compost in 2016 (323 mg.kg^{-1}); the lowest was found in the control treatment in 2011 (173 mg.kg^{-1}). Diacono and Montemuro (2010) documented that the organic fertilisation increases the amount of available nutrients, which finding was demonstrated also in our study. Nevertheless, as it is apparent from Tab. IV, mainly the compost application increased the supply of soil with the available nutrients.

These findings are in line with the results of Šimon and Czakó (2014), who referred that additions of organic matter from various sources, can differ in the effects on soil organic matter and biological activity. Generally, the composts are slowly decomposed in the soil, the continuous release of nutrients can sustain the microbial biomass population for longer periods of time (Murphy *et al.*, 2007).

Application of the organic matter into the soil has also the positive influence on the utilisation of nutrients by the plants (Watson *et al.*, 2002). Organic fertiliser is according to the authors

Montemurro *et al.* (2004) the important source of organic matter, nitrogen and other nutrients. In addition, the organic fertilisation has also ecological and economical importance, because the cycle of nutrients is closed. Our study showed, that the compost application lead to the stabilization of the organic matter, and subsequently there were positively influenced the chemical soil properties, which is in line with Moral *et al.* (2009). Another important advantage of compost lays in the fact, that the use of compost reduces nitrogen (nitrate) losses from the soil as emphasized Plošek *et al.* (2017), which, however, was not the subject of this paper. Equally important is the fact, that the compost contained less potassium and more magnesium than slurry. After application of K fertiliser, potassium supply in soil solution will be temporally plentiful and in this situation the plants take up more K than need for optimum growth. Luxury uptake of K can cause metabolic disorders such as magnesium or sodium deficiency. Miller and Miller (2000) emphasized that the application of organic matter into the soil has not the immediate effect and the improvement of the soil characteristics can be expected in a long-term scale.

CONCLUSION

On the basis of our results we can conclude, that the both types of the organic fertilisers had a positive influence on the chemical soil properties, however, the compost was the better fertiliser than the slurry from this point of view. In 2016, four years after the last application of the organic fertilisers, there were found the better chemical soil conditions in the treatments previously fertilised with the compost. Thus, the application of compost lead to the improvement of the chemical soil properties even four years after cessation of the fertilisation. Furthermore, the use of compost reduces nitrogen losses and leads to increased soil pH.

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