

LONG-TERM ORGANIC FERTILIZATION AFFECTS SOIL PROPERTIES

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Abstract

A long-term small plot trial for the evaluation of organic fertilizers was established in Jeseníky Mountains in the Czech Republic. During ten years period the experiment was fertilized with organic fertilizers (compost, slurry) and was managed with cutting frequency 3 times per year. After ten years management this experimental plot was ceased and the grasslands were completely abandoned. We investigated the direct effect of organic fertilizers and residual effects of long-term organic fertilization on physical and chemical soil properties. After long-term organic fertilization, the increase of nutrients, soil organic carbon, pH was monitored. Furthermore, the residual concentrations of soil available nutrients were higher with organic fertilizers compared to the control. The same trend was observed for physical soil properties. For risk trace elements, there was no difference among treatments and there was no increase during years. In conclusion, the direct and residual effects of organic fertilizers were positive to soil nutrient increase and to ensure soil environmental function.

Keywords: *compost, slurry, soil nutrients, grassland*

1. INTRODUCTION

The organic fertilizers 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 fertilization with mineral fertilizers is not generally necessary in grasslands. The difference is, that the nutrients in inorganic fertilizers can be directly taken up by plants in contrast to nutrients in organic fertilizers, which have to be released by microbial metabolism to make most of them available to plants (Böhme et al., 2005). Another thing is that soil properties such as pH, organic matter contents and available forms of macronutrients, are easily affected by the use of long-term organic fertilizers (Ziogas et al., 2021).

There is an advantage of organic fertilisers which lays in the fact, that their application can positively influence the soil organic carbon content (Gonet & Debska 2006). Application of organic materials such as compost and manure are widely used for their positive environmental impacts (Celik et al., 2010). There is strong positive relationship between the amount of organic matter and physical soil parameters (Guo et al., 2016). Significant improvements in soil physical, chemical and biological properties have been reported in organic matter application systems (Chang et al., 2014).

The results presented by Šimon & Czako (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 fertiliser's application (Diacono & Montemurro 2010) which was, however, only rarely investigated in grasslands.

Another question, which has been frequently asked by scientists (Plesa et al., 2014; Ronch et al., 2013), 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 residual effects of organic fertilizers after long-term application have been recently studied (Ziogas et al., 2021).

The influence of organic fertilisers (cattle slurry, in particular) has been studied by many authors (Lalor et al., 2011; Duffková et al., 2015). 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. On the contrary, slurry is the fertiliser with a quick-release nitrogen because the ratio C:N < 10.

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 soil chemical and physical properties and to assess the residual effects after long-term fertilization with compost and slurry.

2. MATERIALS AND METHODS

2.1. Study sites

The experimental plots with organic fertilisers were initiated in Rapotín in 2004. The experimental site was situated in the Czech Republic (50°00'32"N and 17°00'83"E) 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. Average annual temperature is 7.2°C and annual precipitation 693 mm. The vegetation of the experimental area was classified as *Cynosurion* with some elements of *Arrhenatherion*. 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.

2.2. Plots design

A long-term small-plot experiment (plot size: 12.5 m²) in completely randomised blocks with four replicates was investigated on permanent grassland. Two types of organic fertilisers were applied during 2004–2014: (S) cattle slurry, and (C) compost. Organic fertilisers were used in annual doses of nitrogen: 84 kg/ha, which approximately corresponded to 1.4 LU/ha (LU = livestock unit). The fertilisers were analysed for the content of nutrients before their application. 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 Table 1.

Fertilizer	P	K	Ca	Mg	Cd	Zn	C _{org}
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
slurry	6.61	26.28	11.77	24.93	0.142	329	35
compost	4.24	22.33	20.58	76.27	0.012	273	52

Table 1. Average concentrations of elements in organic fertilisers (in dry matter)

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 three times per year. Treatments of the fertilisation and the cutting regime are given in Table 2.

After ten years, the regular management was ceased and the grasslands were completely abandoned.

Fertilization	Annual dose of nitrogen	Application	1st cut	2nd cut	3rd cut
control (without fertilizers)	—	—	May 30	July 30	Sept. 30
slurry	84 kg/ha	50% of dose in spring 50% of dose after the 1 st cut	May 30	July 30	Sept. 30
compost	84 kg/ha	50% of dose in spring 50% of dose after the 1 st cut	May 30	July 30	Sept. 30

Table 2. Description of treatments with different grassland management (before abandonment)

2.3. Evaluated parameters

Soil samples were taken twice a year (summer and autumn) from experimental plots after 10 years of fertilizing and during three years of abandonment. Sampling was done from a depth 0.05–0.15 m. Evaluated parameters: soil organic carbon (C_{org}); content of nitrogen (N_{tot}); Mehlich III extract (Mg, Ca, P, K); C/N ratio; pH (pH/ $CaCl_2$); total trace elements (Zn, Pb, Cd); bulk density (pd) and porosity (P). Total organic carbon (C_{org}) was determined by elemental analyzer (Primacs100, Skalar). Fractional composition of humic substances (HA and FA) was determined by short fractionation method. Total content of trace elements (Zn, Pb, Cd) were determined after microwave extraction in aqua regia. Macroelements (Ca, Mg, K, P) were detected using by Mehlich III method. Total nitrogen was determined according to Kjeldahl method. The soil reaction pH was determined in solution $CaCl_2$. Physical soil parameters bulk density (pd) and porosity (P) were measured using soil sample steel rings. All methods are described in Zbíral et al. (2016).

2.4. Statistical analyses

Statistical data analysis was undertaken using the statistical program SPSS 13.0 for Windows. Analysis of variance (ANOVA) was performed by statistical program. Mean statistical differences (95% significance level) were calculated by Tukey's HSD test ($P < 0.05$). We tested homogeneity of variances by Cochran–C's test.

3. RESULTS

The mean concentrations of selected soil parameters from 10 years fertilized experimental site are given in Table 3. Statistically significant difference mainly between compost plots and control was found. As it is evident pH, N_{tot} , Ca and P contents were directly influenced by compost fertilizer. Further, it was found, that the fertilisation with compost increased the soil reaction. On average, the highest pH value showed the compost treatments (5.1) compared to the slurry treatments (4.7) and the controls without fertilisation (4.8). This trend was found for N_{tot} , Ca, P contents too.

Organic carbon (C_{org}) was at its maximum on the plot with compost application. There is evident the same effect of compost fertilizing. The qualitative parameters of organic carbon is C/N. Ration C/N was lower than 10 on all plots.

The amount of trace elements weren't influenced by fertilizing. The mean concentrations of measured trace elements were on the low limit.

Treatment	pH	Mg	Ca	K	P	C _{org}	N _{tot}	C/N	Zn	Pb	Cd
		mg/kg	mg/kg	mg/kg	mg/kg	%	%		mg/kg	mg/kg	mg/kg
control	4.8 ^a	173	1944 ^a	159	53 ^a	1.46 ^a	0.18 ^a	8.1	50	8	0.12
slurry	4.7 ^a	185	1954 ^a	155	55 ^a	1.44 ^a	0.17 ^a	8.5	60	7	0.13
compost	5.1 ^b	216	2383 ^b	151	70 ^b	1.61 ^b	0.19 ^b	8.4	52	10	0.13
P	0.03	0.17	0.04	0.84	0.02	0.04	0.04	0.06	0.85	0.75	0.53

Table 3. Average values of selected soil parameters on plots with ten years organic fertilizers application

(^{a, b} - values with the same letter are not statistically different within the column $P < 0.05$)

The experimental plots were abandoned and three years after last management soil samples were taken and analyzed (Table 4). The results from these plots showed similar trends as fertilized plots. Furthermore, statistical significant differences in pH and Ca concentrations were found between compost plots and control and slurry plots. The mean pH values and Ca concentration were similar on abandoned plots as on fertilized plots. The same trend with the highest amount of nutrients and organic matter was found too. The concentration of risk elements was not affected by the management.

Treatment	pH	Mg	Ca	K	P	C _{org}	N _{tot}	C/N	Zn	Pb	Cd
		mg/kg	mg/kg	mg/kg	mg/kg	%	%		mg/kg	mg/kg	mg/kg
control	4.8 ^a	197	1660 ^a	142	50	1.29	0.16	8.06	48	9	0.11
slurry	4.7 ^a	291	1625 ^a	124	61	1.35	0.16	8.44	56	8	0.12
compost	5.1 ^b	321	2323 ^b	114	64	1.39	0.17	8.18	52	11	0.12
P	0.04	0.38	0.04	0.33	0.46	0.52	0.53	0.08	0.49	0.68	0.74

Table 4. Average values of selected soil parameters on plots after cessation of organic fertilization

(^{a, b} - values with the same letter are not statistically different within the column $P < 0.05$)

Physical soil properties showed in Table 5 copied results of chemical parameters. Bulk density was clearly affected by the management. The value of bulk density significantly decreased with compost fertilizing. Furthermore, this significant decrease was observed after abandonment. The lowest values were measured after cessation of fertilizing. The maximum values for porosity were measured after 10 years fertilizing and after abandonment too.

Treatment	pd (g/cm ³)		P (%)	
	fertilizing	abandonment	fertilizing	abandonment
control	1.48 ^a	1.33 ^a	45	50
slurry	1.43 ^{ab}	1.30 ^{ab}	46	49
compost	1.35 ^b	1.22 ^b	48	53
P	0.02	0.03	0.49	0.51

Table 5. Average values of selected soil parameters on Praded experimental locality

(^a, ^b – values with the same letter are not statistically different within the column $P < 0.05$)

4. DISCUSSION

After applying organic fertilizers (specially compost) for a decade pH, organic carbon, nitrogen, some nutrients increased in comparison to the control. Furthermore, the beneficial residual effects of manure application 3 years after the end of the experiment were apparent mainly for pH, content of Ca and bulk density.

Soil pH on experimental plots was typical for grassland in the Czech Republic. The long-term organic fertilizers application can lead to the decrease of soil reaction (Verma & Goyal 2018), however the compost has got the puffer ability and it can soften the soil acidity. Changes in pH may affect another soil properties and soil condition (Ziogas et al., 2021) that is why this impact of organic fertilizing is beneficial.

Application of the organic matter into the soil has also the positive influence on the utilization of nutrients by the plants (Watson et al., 2002). Organic fertilizer is according to the authors (Montemurro et al., 2004) the important source of organic matter, nitrogen and other nutrients. In addition, the organic fertilization 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.

Diacono & Montemurro (2010) documented that the organic fertilisation increases the amount of available nutrients, which finding was demonstrated also in our study. These findings are in line with the results Šimon & Czako (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 (Adugna 2016). This could be explanation of positive residual effect of this fertilizer.

Our findings are in agreement with Whalen & 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. Compost 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 & 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 N was applied. The increase in total soil N content was found also in our study three years after the last fertilisers' application, which was the most apparent in the treatments fertilized with compost. 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, narrower value than 10 means better humus quality and vice versa. Within our study, the value of this ration was below 10 in all treatments.

Concentrations of all analyzed risk elements in soil did not exceed the limits permitted by the Czech national legislation (Sánka & Materna 2004). This is positive information because mainly slurry can sometimes cause higher inputs of microelements, especially zinc (Upreti et al., 2009).

Bulk density is the parameter, which characterizes the degree of the soil compaction. The optimal value for grassland is about 1.4 g/cm. In our study, the lowest values were found for the compost treatments. The benefit of compost is the positive influencing of the physical soil parameters (Celik et al., 2004). Another physical characteristic which expresses the soil status is total porosity. This parameter negatively correlates with bulk density. In our case, we found the highest porosity on the compost plots again. These findings are similar with Meena et al. (2018) who confirmed positive effects of organic fertilizers.

We found residual effects of more than a decade of organic fertilizers application on soil chemical properties, this was accompanied by similar effects on physical properties. There was a trend of increased nutrient values and decrease bulk density with compost application.

5. CONCLUSIONS

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

ACKNOWLEDGMENTS

This study was supported by the Ministry of Agriculture, Czech Republic MZE-RO1218.

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