Influence of long-term application of organic and inorganic fertilizers on soil properties

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ABSTRACT

This study assesses the effect of long-term (59 years) application of organic and inorganic fertilizers on soil organic matter and enzyme activity. Total organic C, total organic N, hot water soluble C, microbial biomass C and dehydrogenase activity were evaluated in soil from the long-term field experiment in Prague-Ruzyně (Orthic Luvisol, clay loam). Total organic C and N increased significantly in soils treated with organic fertilizers (farmyard manure, compost) and in soils with a combination of organic and mineral NPK fertilizers (manure + NPK, compost + NPK, cattle manure + straw + NPK) compared to soil treated with inorganic fertilizer, cattle slurry + straw and non-fertilized control. Farmyard manure significantly increased hot water soluble C compared to the control. Dehydrogenase activity was significantly increased by all treatments compared to control. The results indicate that additions of organic matter from various sources differ in the effects on soil organic matter and biological activity. The effect of manure was the most favourable; long-term application of cattle slurry + straw is rather similar to mineral fertilization.

Keywords: long-term experiment; fertilization; soil organic matter; microbial biomass; dehydrogenase activity

In the Czech Republic, farmyard manure as a source of soil organic matter remains the main organic fertilizer but besides, other organic fertilization as cattle or pig slurry is also used, and recently application of straw became a substantial source of organic matter (Lipavský et al. 2008). In addition, compost and various combinations of organic amendments along with mineral NPK are also used. Manures and fertilizers have similar and large effects on the long-term productivity of soils. Organic fertilization is more complicated than application of mineral fertilizers with exactly known nutrient content. On the other hand, the fertilization value of organic amendment to the soil can be enhanced when proper attention is given to the composition and decisions on rates, timing and placement (Schröder 2005). In contrast to nutrients in organic fertilizers, which have to be released by microbial metabolism to make most of them available to plants, the nutrients in inorganic fertilizers can be directly taken up by plants (Böhme et al. 2005). Many of fertilization effects on the soil become apparent only in long-term field experiments. Changes in soil organic matter (SOM) due to different fertilization practices can be characterized by evaluating a long-lasting increase or decrease in total organic C content in topsoils (Kubát and Lipavský 2006). Our objective was to assess and compare the long-term effect of different organic (farmyard manure, compost, cattle slurry, straw), mineral (NPK) and combined fertilization on quantity (organic C and N) and quality (hot water soluble C, microbial biomass C, hydrophobic organic components derived from fourier transform infrared (FTIR) spectra, dehydrogenase activity) of SOM under specific long-term experiment in Prague-Ruzyně.

MATERIAL AND METHODS

The study site is located in Prague-Ruzyně, Czech Republic (latitude 50°05'15"N, longitude 14°17'27"E). Altitude of the site is 370 m a.s.l. Average annual temperature is 8.2°C and the average annual precipitations are 450 mm. The taxonomical soil unit is Orthic

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Luvisol, clay loam, developed on diluvial sediments mixed with loess (clay content = 27%, pH_{KCl} = 7.0). The long-term field experiment was established in 1955 with the aim to investigate the effect of various fertilization systems on the yields, nutrient uptake and soil quality. The plot size is 12 m × 12 m (144 m^2). Each of 24 treatments has four replicates. Eight fertilization treatments were selected in this study: Control – without organic or mineral fertilization; NPK – mineral fertilization; FYM – farmyard manure; FYM + NPK – farmyard manure + mineral fertilization; Comp – compost; Comp + NPK – compost + mineral fertilization; Csl + St – cattle slurry + straw; Csl + St + NPK – cattle slurry + straw + mineral fertilization. In the experiment, two crops were regularly rotated: sugar beet and spring wheat. Annual doses of organic matter and mineral nitrogen fertilizers applied are shown in Table 1. Soil sampling was carried out annually before mineral fertilization at the beginning of April in the period 2007 to 2012 from topsoil in the depths of 0–20 cm at four sites of each individual plot.

C fractions and total N. Microbial biomass C (C_{mic}) was determined by the chloroform fumigation-extraction method (Vance et al. 1987). Hot water soluble C (C_{hwl}) content in the soil samples was determined according to Schulz (1997). Total organic C (C_{tot}) and total organic N (N_{tot}) were determined on a Vario max analyser (Elementar Analysensysteme GmbH, Hanau, Germany) in air-dried soil samples. The FTIR spectra were measured on the Thermo Nicolet Avatar 320 FTIR spectrometer, equipped by a smart diffuse reflectance accessory (Nicolet, Madison, USA) in a homogenous mixture of bulk soil with KBr (FTIR grade, Aldrich, Germany) (Šimon 2007). The FTIR spectra were analysed at absorption band that indicate the hydrophobic (CH-groups) functional groups. For hydrophobic methyl and methylene groups the CH bands occurred at 3000–2800/cm (Ellerbrock et al. 2005). The area of absorption bands of hydrophobic groups in the FTIR spectra was integrated with spectrometer software (Omnic, version 6a, Nicolet, USA) and defined as intensities.

Enzyme activity. Dehydrogenase activity was measured in soil samples of 6 g that were incubated at 37°C for 24 h in the presence of 3% triphenyltetrazoliumchloride. The red coloured product (triphenylformazan) was extracted with ethanol, and measured in a spectrophotometer at 485 nm (Thalmann 1968). All analyses were made in triplicate and average values were further processed.

Statistics. The basic statistical values i.e. averages and standard deviations (SD) were calculated using Microsoft Excel (Microsoft Corporation, Redmund, USA) and Statistica Cz 8.0 (Stat. Inc. Tulsa, USA). Data for each year were analysed by analysis of variance. Tukey's *HSD* test was used to determine significance of differences among individual treatments. The columns in figures designed by the same letter do not differ significantly ($P < 0.05$).

RESULTS AND DISCUSSION

Total organic C. Average C_{tot} content in the soil in the assessed period ranged from 1.37% to 1.69%. FYM and Comp + NPK increased C_{tot} content significantly (by ~24%) compared with the non-

Table 1. Average annual doses of organic matter and nitrogen input by organic and mineral fertilizers into the selected plots of the long-term experiment

Treatment	Organic matter (t/ha)	Organic nitrogen	Mineral nitrogen	Total nitrogen
		(kg/ha)		
Control	–	–	–	0
NPK	–	–	100	100
FYM	10.5	52.5	–	52.5
FYM + NPK	10.5	52.5	100	152.5
Comp	10	42	–	42
Comp + NPK	10	42	100	142
Csl + St	22.5 + 1.3	42 + 7.8	–	49.8
Csl + St + NPK	22.5 + 1.3	42 + 7.8	100	149.8

Control – without organic or mineral fertilization; NPK – mineral fertilization; FYM – farmyard manure; FYM + NPK – farmyard manure + mineral fertilization; Comp – compost; Comp + NPK – compost + mineral fertilization; Csl + St – cattle slurry + straw; Csl + St + NPK – cattle slurry + straw + mineral fertilization

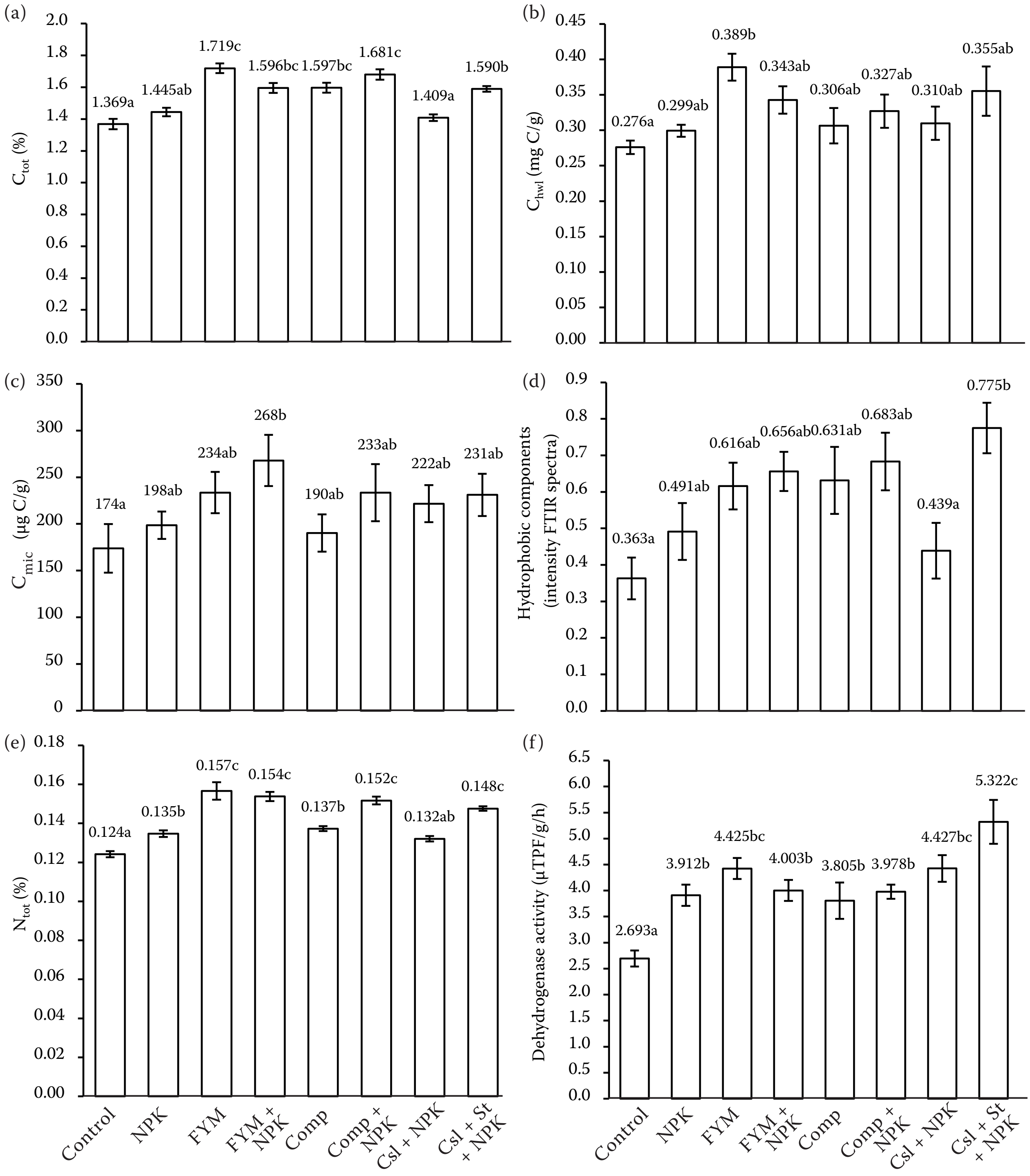

Figure 1. Average (a) total organic C content (C_{tot}); (b) hot water soluble C content (C_{hwl}); (c) microbial biomass C content (C_{mic}); (d) content of hydrophobic organic components; (e) total organic N content (N_{tot}) and (f) dehydrogenase activity in soil samples from plots under different fertilization treatments (experimental site: Prague-Ruzyně, sampled in spring 2007–2012, depth 0–20 cm). Control – without organic or mineral fertilization; NPK – mineral fertilization; FYM – farmyard manure; FYM + NPK – farmyard manure + mineral fertilization; Comp – compost; Comp + NPK – compost + mineral fertilization; Csl + St – cattle slurry + straw; Csl + St + NPK – cattle slurry + straw + mineral fertilization

fertilized variant (Figure 1a). FYM + NPK, Comp and Csl + St + NPK had also a positive effect on the C_{tot} content in the soil and significantly increased the content of C_{tot} that ranged at 16% above the level of non-fertilized variant. On the other hand, an insignificant effect of NPK on C_{tot} content was observed. There are opposing views on the effect of mineral N fertilization on C_{tot} content in the soil (1) mineral N fertilizer promotes N mineralization and can deplete SOM stocks in the course of time and (2) on the contrary, increased plant growth as a result of inorganic N use (compared to no fertilization) increase organic matter inputs and hence SOM stocks (Moeskops et al. 2012). Our results do not provide evidence for a significant effect of mineral NPK on C_{tot} content in soil. Some researches indicate that the application of organic manure in combination with inorganic fertilizer linearly increased soil organic C levels (Böhme et al. 2005, Li et al. 2010). In the present experiment, the addition of mineral NPK fertilizers to compost and cattle slurry with straw increased the C_{tot} content in the soil (by about 7%) but the same addition to FYM was ineffective. Kunzová (2013) found in the same field experiment that there was no substantial difference in the effect of crop rotation on the organic C content in the topsoil.

Hot water soluble C. Hot water soluble C accounts for about 2–5% of the C_{tot} and represents not only microbial biomass C but also root exudates, soluble carbohydrates and aminoacids (Ghani et al. 2003). Similarly to C_{tot} content, all fertilized treatments showed increased C_{hwl} content in topsoil as compared with non-fertilized control (Figure 1b). The largest significant increase of C_{hwl} was recorded in treatment with FYM amendment (by 41%); effect of other treatments was also positive, but not statistically significant. C_{hwl} accounted for 1.91–2.26% of total organic C, higher values were calculated for FYM and Csl + St + NPK. The addition of mineral N increased the percentages of C_{hwl} in C_{tot} in Comp + NPK and Csl + St + NPK. Similarly as in C_{tot} content, addition of mineral N to FYM did not increase the C_{hwl} content. C_{hwl} relates well with microbial biomass C (Sparling et al. 1998). Loss of C_{hwl} can indicate a decline of microbial biomass pool, its activity and soil fertility in general (Ghani et al. 2003).

Microbial biomass C. Soil microbial biomass represents 1–4% of C_{tot} and as the living part of SOM it is responsible for nutrient transformation and storage (Nieder et al. 2008). C_{mic} content within the assessed time period ranged from 173.8 to 267.9 µg/g soil; low C_{mic} was found in the control and only NPK fertilizer treatments (Figure 1c). Low values of C_{mic} content were determined also in treatment with compost. High quality compost brings into the soil stabilized organic substances which are not subjected to further degradation. On the contrary FYM and especially FYM + NPK increased C_{mic} content by 54% compared with the non-fertilized variant, which was a significant increase. These results are consistent with previous observations which documented that microbial biomass was considerably greater in soils receiving farmyard manure (Hao et al. 2008, Liu et al. 2010) and FYM + mineral N (Mandal et al. 2007) than in plots receiving only NPK fertilizers. In the long-term period, large amounts of C inputs from manure became gradually stabilized in the soil (Ding et al. 2012). An significant increase of C_{mic} (by about 27–33% compared to non-fertilized control) was recorded also after application of Csl + St and Csl + St + NPK.

Hydrophobic organic components of SOM. Average intensities of hydrophobic components derived from FTIR spectra for individual treatments are shown in Figure 1d. All kinds of fertilization increased the amount of hydrophobic components in SOM as compared to non-fertilized variant. Long-term application of cattle slurry + straw + NPK to the soil significantly increased the amount of hydrophobic components in SOM more than twice compared to control; other organic amendments (FYM, Comp) had also increasing effect. Addition of mineral NPK to organic material strengthened this influence. Harper et al. (2000) and McKissock et al. (2003) showed that farming which increased the organic C content in the soil might increase the hydrophobicity (water repellency) and reduce soil wettability. Results of our study are consistent with these findings.

Total organic N. Periodical input of mineral and organic fertilizers increased significantly the N_{tot} content in assessed time period compared with control variant similarly to C_{tot} content (Figure 1e). Mineral NPK fertilization increased N_{tot} content by about 8.6% whereas FYM amendment increased N_{tot} content by 26.3%. The addition of mineral N fertilizers to FYM, compost and cattle slurry increased the average annual doses of delivered nitrogen per ha by 100 kg (Table 1). Such addition increased N_{tot} content in the soil in Comp + NPK treatment by 11.6% and in Csl + St + NPK by 12.5%. Addition of NPK to FYM has rather a negative effect, and N_{tot} content in FYM + NPK treatment was lower than in FYM treatment. It seems that certain part of mineral nitrogen was probably lost from soil by denitrification, volatilization or leaching (Meng et al. 2005). Remaining part of the nitrogen in NPK treatment was directly utilized by plants, similarly as in variant with Csl + St which contains N in an ease mineralizable form. Long-term fertilization with manure contributed significantly to the increase in the total nitrogen content in the soil, which can be made available via gradual mineralization.

Dehydrogenase activity. Dehydrogenase activity is only present in viable cells and reflects the total range of oxidative activity of soil microflora (Kanchikerimath and Singh 2001). Activity of dehydrogenase in topsoil in the selected treatments of the long-term field experiment is presented in Figure 1f. All kinds of fertilization increased significantly dehydrogenase activity above the level of non-fertilized variant. The highest dehydrogenase activity was determined in Csl + St + NPK (by 97.6% compared to control). Addition of NPK to straw combined with cattle slurry evidently increased soil enzyme activity and straw decomposition compared to treatment without mineral NPK addition. Application of straw + N in similar long-term experiment in Trutnov increased microbial biomass C content in soil and generated invertase activity above the level of FYM (Šimon et al. 2013). Mandal et al. (2007) showed that easily decomposable components of crop residues may have a strong effect on dehydrogenase activity and metabolism of soil microorganisms. On the contrary, dehydrogenase activity is less influenced or even inhibited by separate mineral nitrogen fertilization (Saha et al. 2008). In our experiment, no inhibitory effect of mineral NPK to dehydrogenase activity was observed. The results obtained in this study indicate that almost 60 years of continual fertilization with mineral and organic fertilizers affected soil properties in different ways. While mineral fertilization and application of cattle slurry had no statistically significant effect on the most of monitored characteristics, FYM improved both the quantity and quality of soil organic matter. Moreover, addition of mineral NPK to compost and even to cattle slurry + straw increased the effect of these amendments on organic C and N content in soil and soil enzyme activity.

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