Influence of long-term fertilizer application on changes of the content of Mehlich-3 estimated soil macronutrients

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ABSTRACT

The aim of this work is to evaluate the changes of Mehlich 3 – P, K, Ca and Mg contents in soil during a long-term field experiments with sewage sludge, farmyard manure (FYM) and mineral NPK (NPK) application, compared to the control non-fertilized treatment. The experiment was established at the Humpolec and Suchdol sites (Czech Republic). Potatoes, wheat and barley were grown in crop rotation. Fertilizing system was based on the same nitrogen dose of 330 kg N/ha per one crop rotation. Archive soil samples from the beginning of the experiment (1996) and from the end of each year's crop rotation (1999, 2002, 2005, 2008 and 2011) were analyzed. In spite of the different soil-climatic conditions of the studied sites, very similar tendencies of P, K, Ca and Mg contents changes after the fertilizing systems used were observed in the soil. In case of the same nitrogen dose (330 kg N/ha), sewage sludge appeared to be better source of bioavailable soil phosphorus compared to the farmyard manure and NPK. On the contrary, FYM was a better source of bioavailable potassium and magnesium, despite the lower total magnesium content in FYM. The NPK treatment was the best long-term source of bioavailable potassium.

Keywords: soil; sewage sludge; farmyard manure; mineral NPK; bioavailable P, K, Ca, Mg

For the future it is important to understand the influence of fertilizer application on the nutrient dynamics in soil as well as its influence on the plant growth in more detail. The content of bioavailable nutrients in soils varies not only depending on the fertilizer used, but also on the seasonal influence, soil properties and many other factors. Therefore, the data of the long-term field experiments provide valuable information about the fertilizing optimization possibilities. The importance of long-term field experiments is mentioned in many papers (f.e. Johnston 1997, Černý et al. 2010, Hejcman et al. 2012).

This experiment is focused especially on the evaluation of long-term sewage sludge (SS) and farmyard manure (FYM) application on Mehlich-3 estimated macronutrients (P, K, Ca and Mg) content changes, compared to the mineral NPK (NPK) and control non-fertilized treatments. A positive effect of farmyard manure application on crop yield, soil properties and macronutrient content in soil was observed in numerous studies (Barzegar et al. 2002, Troeh and Thompson 2005, Bhattacharyya et al. 2007). Organic fertilizers may be replaced with straw left in the field after the harvest of cereals, although the effect of straw application on yield reported in literature is rather low (Powlson et al. 1985, Thomsen and Jensen 1994). Another alternative to the application of organic matter and nutrients may be fertilization with stabilized sewage sludge from waste water treatment plants. In numerous publications sewage sludge is described as a source of nitrogen and phosphorus (Petersen et al. 2003, Balík et al. 2007, Huang et al. 2012),

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which favor yield formation of crops (Christie et al. 2001). On the other hand, studies about the influence of sewage sludge on the other macronutrients content in soil and plants appear only seldom (Warman and Termeer 2005a,b, Chowaniak and Gondek 2009).

Mehlich-3 is a widely used method to extract plant-available phosphorus from soil over a wide range of pH value (Sims et al. 2002, Schroder et al. 2009, Zhang et al. 2009). It is one of the strongest extractants to estimate bioavailable nutrients from soils (Kulhánek et al. 2009). The method is also used by many laboratories to determine multiple plant-available nutrients simultaneously. Based on the interlaboratory tests it is possible to successfully use the method to determine K, Mg, Zn, Mn and Cu, respectively, but the results of Ca measuring are often not repeatable (Schroder et al. 2009).

The aim of this research work is to evaluate the influence of long-term application of different fertilizing systems (sewage sludge, farmyard manure and mineral NPK) on the Mehlich 3-bioavailable soil P, K, Ca and Mg contents changes.

MATERIAL AND METHODS

The long-term field experiment was based on experimental fields of the Czech University of Life Sciences in Prague and Crop Research Institute in Prague-Ruzyně, Czech Republic. The characteristic of the sites are given in Table 1.

Potatoes, winter wheat and spring barley were planted in crop rotation on small plots (60 m^2). Organic fertilizers were applied only to potatoes in the crop rotation. Therefore, the direct influence of organic fertilizers application could be observed on potatoes. For winter wheat and spring barley only the consequential influence could be observed. The total amounts of P, K, Ca and Mg applied per one crop rotation in different fertilizing treatments are summarized in Table 2.

For this experiment, sewage sludge from a wastewater treatment plant in Prague was used. The whole system of fertilizing is based on the uniform ratio of 330 kg N/ha per 3 years. That applies for organic and mineral fertilizers as well.

Archive air dried soil samples (< 2 mm) from the beginning of the experiment (1996) and from the end of each crop rotation (years 1999, 2002, 2005, 2008 and 2011) were chosen for the analysis. All the samples were taken after the harvest of the above mentioned crops and before organic fertilizer application. The soil samples were extracted according to the Mehlich-3 method (Mehlich 1984). Each sample was analyzed in two replications. The content of phosphorus was measured using inductively coupled plasma – optical emission spectroscopy (ICP-OES, Agilent Technologies 720, USA). The contents of K, Ca and Mg were measured using atomic adsorption spectroscopy (AAS, Varian 280 FS, Victoria, Australia).

RESULTS AND DISCUSSION

In order to eliminate the plots variability, the data from the year 1996 (before start of the experiment) were converted to 100%. The data from the following years were then compared with the year 1996. We usually did not find significant differences in the obtained results between the crops in crop rotation. Therefore the mean value of the P, K, Ca and Mg content in soil from all three crops together was calculated.

Figure 1 shows changes in soil P, K, Ca and Mg contents at the Humpolec site. The phosphorus contents in the year 1996 ranged between 59 and 89 mg P/kg. Sewage sludge appeared to be the best source of bioavailable phosphorus in soil. The P content increased from 100% in the year

Table 1. Characteristics of experimental fields

	Humpolec	Suchdol
Latitude	49°33'15"N	50°07'40"N
Longitude	15°21'02"E	14°22'33"E
Altitude (m a.s.l.)	525	286
Mean yearly temperature (°C)	7.0	9.1
Mean yearly rainfall (mm)	665	495
Soil type	cambisol	chernozem
Soil sort	sandy loam	loamy
pH[1]	5.1	7.5
P (mg/kg)[2]	77 (± 10)	74 (± 9)
K (mg/kg)[2]	238 (± 47)	209 (± 18)
Ca (mg/kg)[2]	1625 (± 187)	7803 (± 1760)
Mg (mg/kg)[2]	112 (± 14)	209 (± 16)

[1]Estimated in 0.01 mol/L $CaCl_2$, 1:10 w/v; [2]Average basic data estimated using Mehlich-3 method in archive samples (1996)

Table 2. Application rates of nutrients (kg/ha) – 3-year cycle

Treatment		Potatoes	Wheat	Barley
Control	N, P, K, Ca, Mg	0, 0, 0, 0, 0	0, 0, 0, 0, 0	0, 0, 0, 0, 0
Sewage sludge	N	330[1]	0	0
	P	201[1]	0	0
	K	55[1]	0	0
	Ca	268[1]	0	0
	Mg	70[1]	0	0
Farmyard manure	N	330[1]	0	0
	P	70[1]	0	0
	K	352[1]	0	0
	Ca	250[1]	0	0
	Mg	30[1]	0	0
NPK	N	120	140	70
	P	30	30	30
	K	100	100	100
	Ca, Mg	35, 0	47, 0	21, 0

[1]Dose was calculated based on the average nutrient content in organic fertilizers; [2]Mineral fertilizers: N – calcium ammonium nitrate (27% N, 8% Ca); P – triple super phosphate (21% P); K – potassium chloride (50% K)

1996 to 233% in the year 2011. That was caused due to the high total amount of P added in sewage sludge compared to the other fertilizer treatments. Whole experiment was based on the same N dose. The average P contents in sewage sludge dry mass ranges between 1.71% and 2.35% (Mosquera-Losada et al. 2010). The sewage sludge applied to our experiment contained 2.20% P. On the contrary,

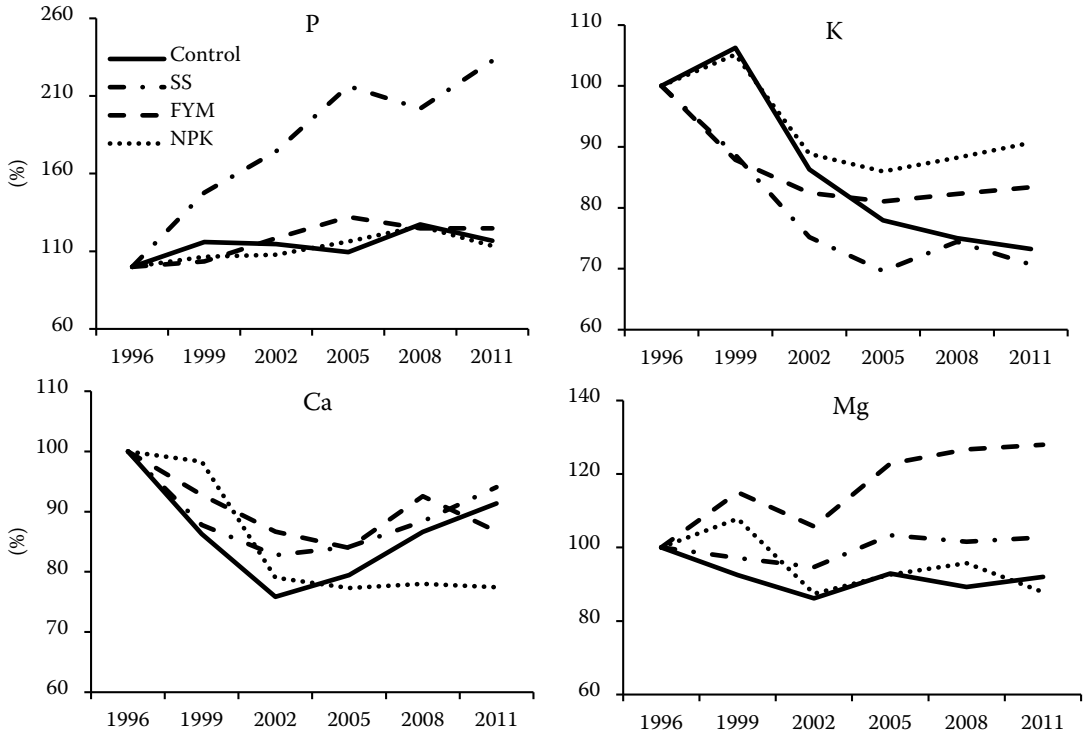

Figure 1. Changes of available soil P, K, Ca and Mg contents at Humpolec site. SS – sewage sludge; FYM – farmyard manure; NPK – mineral NPK

farmyard manure contained only 0.46% P in dry mass. That resulted in a total application dose of 201 kg P/ha per crop rotation (SS) and only 70 kg P/ha per crop rotation (FYM), respectively. Sewage sludge phosphorus availability is comparable with superphosphates (Coker and Carlton-Smith 1986). Therefore, such a big increase of bioavailable P content during the experiment was observed. The increasing tendency was visible at the other fertilizer treatments as well, but there were only slightly differences compared to the control non-fertilized treatment. Sewage sludge as a good source of available phosphorus compared to another organic fertilizers was reported by Petersen et al. (2003) as well. Based on the results of Huang et al. (2012) the P availability strongly depends on stabilization and P-precipitation processes.

Soil potassium contents ranged between 157 and 331 mg K/kg in the year 1996. A decreasing tendency in all treatments is visible. The K content in the NPK treatment decreased to 91% in the year 2011 compared to the 100% in the year 1996. The further decrease was observed at the treatment farmyard manure. Average K content gradually decreased to 83% in the year 2011. To the FYM treatment 17 kg K/ha more was yearly added than to the NPK treatment. However, the lower contents of bioavailable K in soil were found at the FYM treatment in the year 2011. Troeh and Thomson (2005) reported that the long-term farmyard manure application increase the soil sorption capacity. Potassium could be also more easily fixed to the non-available forms. Therefore, the estimated contents of bioavailable potassium were lower compared to the highly soluble K applied in NPK treatment at the end of experiment. However, Černý et al. (2010) published that NPK fertilizing resulted in higher crop yields. They reported in average about 29% higher yields of wheat and barley and 6% higher yield of potatoes compared to the FYM treatment at 5 experimental sites. This probably resulted in higher K uptake. The first mentioned fact had also probably stronger influence than the K uptake by plants.

The treatment amended with sewage sludge was comparable with control treatment in the year 2011. The measurements were only 73% (SS) and 71% (control), respectively. That was probably caused due to the low K content in sewage sludge compared to the high total N content (whole experiment was based on the same nitrogen dose). The total average content of nitrogen and potassium in sewage sludge applied to our experiments was 3.70% N and 0.60% K in dry mass, respectively. Similar N:K ratios are mentioned in other publications as well, for example 2.82% N and 0.44% K published by Bozkurt and Yarilgac (2003) or 2.20% N and 0.47% K (Antolín et al. 2005). Wen et al. (1999) estimated only 2.00% N and 0.10% K in sewage sludge dry mass. It was probably caused due to the less effective dewatering process used. On the contrary, the contents of nitrogen and potassium in farmyard manure are mutually comparable. Farmyard manure with average content of 2.00% N and 2.17% K in dry mass was applied in our experiment. Similar values are reported in many studies (Petersen 2003, Liu et al. 2010, Citak and Sonmez 2011 and others).

The total yearly potassium content added in the form of sewage sludge was also only 55 kg K/ha per 3 year crop rotation in our experiment, compared to the farmyard manure (352 kg K/ha/3 years) or NPK (300 kg K/ha/3 years).

The overall decreasing tendency of bioavailable potassium content in soil at the Humpolec site can be explained with the soil properties. There are much higher K losses in sandy soils compared to the loamy soils. Alfaro et al. (2004) reported the total K losses about 19 kg K/ha/6 months season on sandy soils and only 1 kg K/ha/6 months season on loamy soils, respectively. Their results were estimated at the fields with permanent grassland system, where are expected the lower K losses than in our experiment.

There were usually no visible tendencies between the calcium contents changes during the period of experiment. The measured values in the samples from the year 1996 ranged between 1532 and 2028 mg Ca/kg. Similar to the potassium content, a decreasing tendency was observed during the experiment.

Compared to the year 1996 (100%), the highest decrease (77%) was observed in the year 2011 in the NPK treatment. It can be partly explained due to the lower content of calcium applied (compared to FYM and NPK). The second reason are the higher calcium losses on loamy-sand compared to the loamy soil (Blume et al. 2002) and the third reason is acidifying effect of calcium ammonium nitrate applied (Vaněk et al. 2012), because of soil acidification is in positive correlation with Ca leaching (Pierson-Wickmann et al. 2009). These facts together with lower Ca uptake at control treatment resulted in the lower soil Ca contents at the NPK treatment in comparison with control non-fertilized treatment in the year 2011.

The magnesium content ranged between 93 and 132 mg Mg/kg at the start of the experiment. The content increased after the long-term farmyard manure application from 100% in 1996 to 128% in 2011. There were almost no changes in the Mg content of the treatment fertilized with sewage sludge during the experiment. On the contrary, a slightly decreasing tendency in soil Mg content of the NPK and control treatments was observed.

Figure 2 shows changes in soil P, K, Ca and Mg contents at the Suchdol site. Phosphorus contents increased always after fertilizer application. The average P value was 74 mg P/kg in the year 1996. The highest increase followed after long term sewage sludge application. Similarly to the Humpolec site, the P content in soil increased from 100% in the year 1996 up to 237% in the year 2011. After Kidd et al. (2007) the long-term application of sewage sludge led to the bioavailable P content increase as well. The application of farmyard manure resulted in an increased P content in soil. The average value in the year 2011 was 52% higher in comparison to 1996. Application of NPK in mineral form during the experiment led to the increase of P content by 25%. The average bioavailable P contents of the control treatment stayed almost unchanged during the experiment.

The contents of available potassium in soil ranged between 184 and 241 mg K/kg. On the contrary to the Humpolec site, there was an increasing tendency of the K content in the soil of all fertilizing treatments during the experiment. The highest increase compared to the year 1996 was observed in the NPK treatment (135%), followed by the FYM treatment (125%), control treatment (110%) and SS treatment (106%), respectively. On the contrary Warman and Termeer (2005b) reported the sewage sludge as a potentially good source of K for crop production. The overall increasing tendency in K content during the experiment can be explained by soil properties mentioned sooner at the Humpolec site description.

The calcium content at the Suchdol site was approximately 3.5 times higher than at the Humpolec site. The values in the wide range between 6348 and 8577 mg Ca/kg were obtained in the samples from the year 1996. Because of high natural soil Ca content, fertilizing probably did not have a significant influence on the bioavailable Ca contents changes during the experiment (on the contrary to the Humpolec site). There are no visible tendencies in soil Ca content changes during the experiment. One of the reasons can be the fact, that some authors do not recommend the Mehlich-3 method to estimate Ca content in soil as well (Schroder et al.

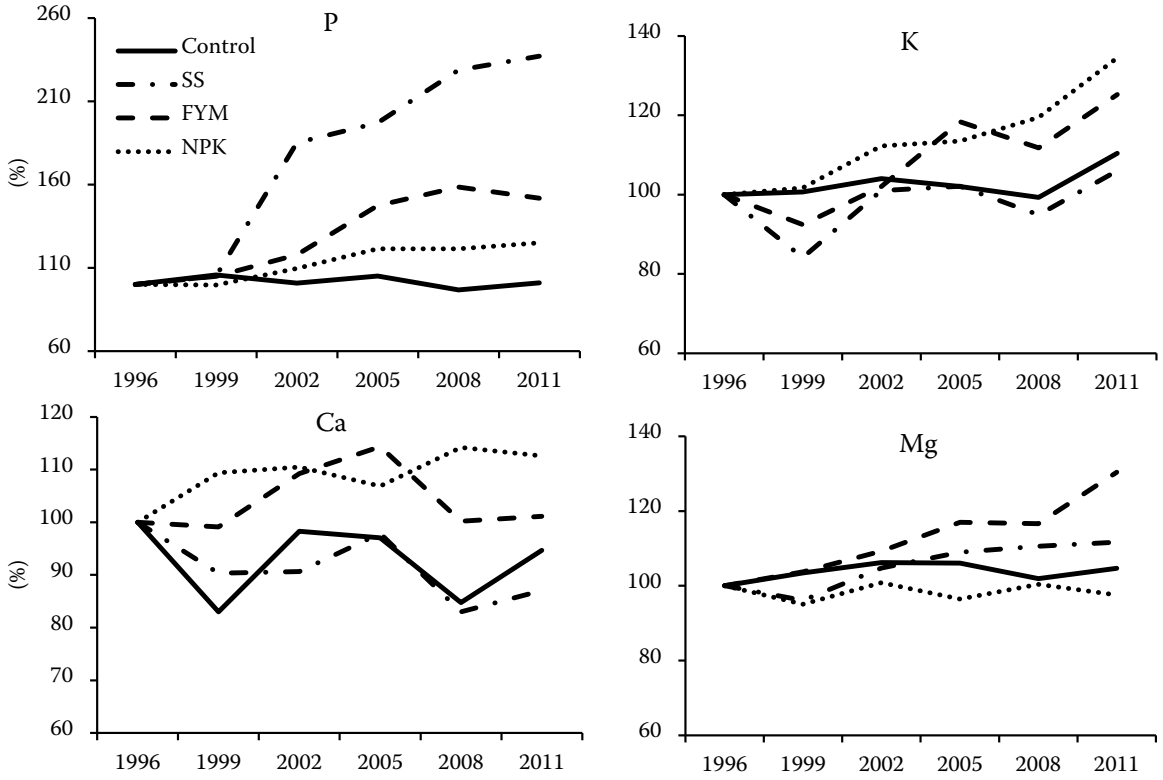

Figure 2. Changes of available soil P, K, Ca and Mg contents at Suchdol site. SS – sewage sludge; FYM – farmyard manure; NPK – mineral NPK

2009). However, the samples from our experiment were measured in one laboratory within two days in two replications. The measurement errors also should be eliminated.

The soil bioavailable magnesium contents had very similar tendencies to change as at the Humpolec site. The highest increase was observed in the FYM treatment. The Mg content increased by 30% in the year 2011 compared to 1996, followed by sewage sludge with 12% increase. The soil Mg amounts of the treatments NPK and control almost did not changed during the experiment. The interesting fact is that the highest increase was obtained in the FYM treatment at both experimental sites, although the higher total Mg content was applied to the SS treatment. Similar results were published by Chowaniak and Gondek (2009). They compared farmyard manure, sewage sludge and mineral fertilizers application in the incubation experiments. Based on their study, the intensity of changes related with Mg transformations strongly depends on the soil properties.

On the contrary to the different soil-climatic conditions of the studied sites, very similar tendencies in the soil of P, K, Ca and Mg contents changes after the fertilizing systems used were observed. At the same nitrogen dose (330 kg N/ha), sewage sludge appeared to be a better source of bioavailable soil phosphorus compared to the farmyard manure. On the contrary, FYM was a better source of bioavailable potassium and magnesium, despite the lower total magnesium content applied in FYM. It was not possible to deduce the tendency in soil calcium content changes during the experiment at both sites. The mineral NPK treatment was the best long-term source of potassium compared to the other studied fertilizing systems.

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