https://doi.org/10.17221/175/2018-SWR

Changes of soil bioavailable phosphorus content in the long-term field fertilizing experiment

Martin Kulhánek[1]*, *Jindřich Černý*[1], *Jiří Balík*[1], *Ondřej Sedlář*[1], *Filip Vašák*[2]

[1]*Department of Agro-Environmental Chemistry and Plant Nutrition, Faculty of Agrobiology Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*Administration of State Material Reserves, Prague, Czech Republic*
**Corresponding author: kulhanek@af.czu.cz*

Citation: Kulhánek M., Černý J., Balík J., Sedlář O., Vašák F. (2019): Changes of soil bioavailable phosphorus content in the long-term field fertilizing experiment. Soil & Water Res., 14: 240–245.

Abstract: The aim of this study is to describe the changes of bioavailable phosphorus content in soil in long-term 18 years field experiments with different fertilizing systems. The field experiments are located at three sites with different soil and climatic conditions in the Czech Republic (Červený Újezd, Humpolec and Prague-Suchdol). Same fertilizing systems and crop rotation (potatoes (maize) – winter wheat – spring barley) are realized at each site with following fertilizing treatments: (1) unfertilized treatment (control), (2) farmyard manure (FYM), (3) and (4) sewage sludge (SS 1 and SS 3), (5) mineral nitrogen (N), (6) mineral nitrogen with straw (N + straw) and (7) mineral nitrogen with phosphorus and potassium (NPK). The long-term fertilizing effect on available P content changes in soil was observed. Bioavailable phosphorus content in soil increased in treatments with organic fertilization after 18 year experiment at all sites. The treatments SS 3 had the highest increase at all sites. The highest bioavailable P content increase compared to control (258 mg/kg) was determined at site Červený Újezd. On the contrary, available phosphorus content decreased at treatments with mineral fertilization and control treatment among all sites. Bioavailable P content decrease in the treatment NPK was observed, although phosphorus was applied. The lowest differences in available P content among all fertilizing treatments were observed at the location Prague-Suchdol.

Keywords: farmyard manure; mineral fertilizing; sewage sludge; soil

Phosphorus (P) belongs to the most important building nutrients and it take part in many life processes (Troeh & Thompson 2005). P concentrations in soils depending on soil horizon (subsoil < topsoil), texture (sandy < loamy), pedogenesis (older < younger), land use (forest < pasture < arable land) and its intensity (extensive < intensive) (Kruse *et al.* 2015). The P adsorption capacity of soil is controlled by several attributes, such as the amount and the type of clay minerals, organic matter, iron and aluminium oxides, and soil pH (Souza *et al.* 2010). Alkine and strongly acid soil reaction depress the bioavailability of phosphorus (Kondratowicz-Maciejewska & Kobierski 2011). Pierzynski *et al.* (2005) reported that total P in most agricultural soils ranges from 50 to 1500 mg/kg, whereas Lindsay (1979) indicated that total P in soils ranges from 200 to 5000 mg/kg. However, only very small ratio of P in soils is available to plants. Organic sources of P are known to long-term increase P availability more than inorganic P fertilizers and enhance efficient use of applied P fertilizer (Mohanty *et al.* 2006). Bioavailable phosphorus content in soil is one of the important indicators of the cultivated land

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QJ1530171.

https://doi.org/10.17221/175/2018-SWR

fertility, which could supply phosphorus nutrient for crop growth. Monitoring soil available phosphorus content in the cultivated land is significant for fertility adjustment, yield improvement and sustainable development of agriculture (Gu *et al.* 2016).

The Mehlich-3 (M3) method is widely used for extraction of plant-available phosphorus from soil over a wide range of pH values (Kobza & Gáborík 2008; Schroder *et al.* 2009; Zhang *et al.* 2009; Kobza *et al.* 2011; Káš *et al.* 2016). Based on the results of interlaboratory determination of available P reported that the method Mehlich-3 is accurate and precise for the determination of available P in soils (Zhang *et al.* 2009). Statistically significant linear relationships between Mehlich-3 and Mehlich-2, Olsen, CAL, and 0.01 M $CaCl_2$ were found and these methods to accurately determine all criteria are able determination of P supply (Zbíral & Němec 2002; Kulhánek *et al.* 2009). Zamuner *et al.* (2006) reported strong positive correlation between Bray 1 and Mehlich-3 extractanting procedures in soils with moderate to slightly acidic pH values.

The aim of this research work is to evaluate the influence of long-term application of different fertilizers (sewage sludge, farmyard manure, mineral N with straw, mineral N and mineral NPK) on the change of bioavailable phosphorus content in soil.

MATERIAL AND METHODS

The bioavailable phosphorus content changes in long-term field experiments were observed at three sites – Červený Újezd, Lukavec and Praha-Suchdol (Suchdol) with different soil and climatic characteristics (Table 1). Potatoes, winter wheat and spring barely were grown in the crop rotation. At the site in Červený Újezd silage maize is included to the crop rotation instead of potatoes because of agronomical conditions of the experimental site. The size of each experimental plot is 60.0 m^2 at the site Lukavec, 60.5 m^2 at Suchdol site and 80.0 m^2 at Červený Újezd site. The same fertilizing systems are used at all sites. Following treatments were studied: control, Sewage sludge 1 (SS 1), Sewage sludge 3 (SS 3), Farmyard manure (FYM), mineral N, mineral N + straw, mineral NPK. Organic fertilizers are applied once every three years in autumn before the potatoes (silage maize). Mineral fertilizers with phosphorus (in the form of triple superphosphate 21% P) and potassium (in the form of potassium-chloride 50% K) were applied yearly in autumn. Nitrogen is applied yearly in the form of calcium ammonium nitrate (27% N) in spring. Fertilizing system and nutrients doses during crop rotation are shown in Table 2.

The content of bioavailable phosphorus were determined from archive composite soil samples taken at experiments establishment before the first fertilizer application in year 1996 and from soil samples taken after of end the crop rotation i.e. spring barley in the year 2013. The soil samples in the year 2013 were collected by Stratified systematic unaligned sampling when from each parcel were taken four soil samples collected from six subsamples taken into circle of radius 30 cm. The soils samples from arable layer (0–30 cm) were collected using soil probe. The soil samples were air dried at the constant temperature of 30°C. Dry soil samples were sieved throrough a 2-mm mesh. The soil samples were extracted ac-

Table 1. Soil and climatic conditions

Sites	Červený Újezd	Lukavec	Praha-Suchdol
Location	50°4'22''N, 14°10'19''E	49°33'23''N, 14°58'39''E	50°7'40''N, 14°22'33''E
Elevation (m)	398	610	286
Average annual temperature (°C)	7.7	7.7	9.1
Average annual rainfall (mm)	493	666	495
Soil type (WRB 2015)	haplic Luvisol	stagnic Cambisol	haplic Chernozem
NRSC USDA	silty loam	sandy loam	silty loam
CEC (mmol(+)/kg)	118	45	262
C_{ox} (%)	1.17	1.27	1.55
Clay (%) (< 0.002 mm)	5.4	3.2	2.2
Silt (%) (0.002–0.05 mm)	68.1	37.1	71.8
Sand (%) (0.05–2 mm)	26.5	59.7	26.0

NRSC USDA – Natural Resources Conservation Service, USDA; CEC – cation exchange capacity; C_{ox} – total organic carbon

https://doi.org/10.17221/175/2018-SWR

Table 2. Nutrients rate during one crop rotation (kg/ha)

Treatment	Potatoes/maize			Wheat			Barley		
	N	P	K	N	P	K	N	P	K
Control	–	–	–	–	–	–	–	–	–
SS	330[1]	303[2]	59[2]	0	0	0	0	0	0
SS 3	990[1]	909[2]	177[2]	0	0	0	0	0	0
FYM	330[1]	113[2]	326[2]	0	0	0	0	0	0
N	120	0	0	140	0	0	70	0	0
N + straw	138	6[2]	47[2]	140	0	0	70	0	0
NPK	120	30	100	140	30	100	70	30	100

[1]total nitrogen in organic fertilizers; [2]average dose based on the nutrients content of fertilizers; SS, SS 3 – sewage sludge; FYM – farmyard manure

cording to the Mehlich-3 method (Mehlich 1984) to obtain the content of bioavailable phosphorus. Each sample was analysed in two replications. The content of phosphorus was measured using inductively coupled plasma – optical emission spectroscopy (ICP-OES, Agilent Technologies 720, USA). The results bioavailable phosphorus content from 2013 were statistically analysed using the Statistica 12.0 software (StatSoft, USA). The one-way ANOVA and Tukey's tests were used to determine significant differences among the treatments.

RESULTS AND DISCUSSION

The available phosphorus content values at the start experiments in the year 1996 from all sites and all treatments are presented in Table 3. The content of bioavailable phosphorus at the start of the experiment in 1996 ranged between 117 and 174 mg/kg at Červený Újezd site, between 187 and 204 mg/kg at site Lukavec and between 63 and 93 mg/kg at site Praha-Suchdol.

At the all organic fertilizing treatments (SS 1, SS 3 and FYM), available phosphorus content increased after 18 year of observation (Table 4). The increased content of available P is related to organic matter which was applied in organic fertilizers and positive balances of phosphorus in organic treatments when the amount of applied P exceed P uptake by plants. The increase of bioavailable P content in SS 1 and SS 3 treatment was caused due to the high dose of phosphorus applied in sewage sludge. The sewage sludge had average content of total phosphorus 3.0% in dry mass. This is more than 2.5% which reported Sommers (1977). Increase bioavailable phosphorus after application sewage sludge was published by many authors. For example Arvas *et al.* (2011) already observed after one year significant increase bioavailable phosphorus by the sewage sludge application (dose of P in sewage sludge 5.1 kg/ha and 7.7 kg/ha) compared with the control. Wu *et al.* (2012) described increase of available P content about 128 mg/kg compared with control after 12 year sewage sludge application with dose of 90 t/ha/year (content of total P 3.47%). The biggest available P content increase was ascertained at treatment SS 3 at all sites which was caused due to the higher dose of sewage sludge. Nogueirol *et al.* (2015) also published increasing content 56.7, 68.8, 125.2 and 169.0 mg/kg of bioavailable P with increasing doses 0, 65, 130, and 207.5 t/ha of sewage sludge (content of total P 1.1%) in 13-year field experiment.

The FYM treatments had higher available P content than mineral treatments including NPK treatment.

Table 3 Available phosphorus content (mg/kg) at the start of experiments in the year 1996

	Control	SS	SS 3	FYM	N	N + straw	NPK
Č. Újezd	119	118	111	117	142	174	166
Lukavec	198	193	196	187	202	197	204
Suchdol	96	72	89	69	69	63	68

SS, SS 3 – sewage sludge; FYM – farmyard manure

https://doi.org/10.17221/175/2018-SWR

Higher content of bioavailable P in FYM in comparison with NPK was due the higher positive balance of P in FYM treatment at each site. Nest *et al.* (2014) also published on base 8-year field experiment statistically significant higher content of available P in FYM treatment (dose of 62 kg P per ha/year) in comparison to mineral NPK treatment (dose of P 42 kg/ha/year). The available P content increase was caused due to the fact that P applied with FYM was in slightly soluble organic form. Organic matter applied in farmyard manure participated on the increase of phosphorus bioavailability in FYM treatments. Humic acids (contained in FYM) could limit sorption of phosphorus, because humic acid participate the sorption places on the active surface of the soil and increase the release of phosphorus to soil (Mikulasova *et al.* 1997). Higher content of available phosphorus after application humic acids with monocalcium phosphate in comparison with monocalcium phosphate application only in laboratory incubation test were observed (Du *et al.* 2013). Kondratowicz-Maciejewska and Kobierski (2011) on base 22 year field experiment reported significant increase of available phosphorus content in soil with increase of farmyard manure dose. Eghball (2002) also recommended adding compost or manure to increase bioavailable phosphorus content.

Content of bioavailable phosphorus in mineral and control treatments decreased in all treatments after 18 years (Table 4). Content of available phosphorus decreased due to the P uptake by plants and not sufficient P dose in N, N + straw and control treatments as well. Higher decrease of available P content was observed in N treatment in comparison to N + straw treatment due to the P application in straw and greater microbial activity, which is participating on the releasing of available P. Liu *et al.* (2010) observed increase microbial activity after 30 years of straw application. Negative balance of P in the treatment N + straw in comparison to N only was observed at each site. Decrease of available phosphorus content in NPK treatment was caused due to the higher yields and for this reason higher P uptake by plants than in organic treatments. Higher yields on mineral treatment on this experiment were documented by Černý *et al.* (2010). Skwierawska *et al.* (2008) also reported decrease of available P content in control treatment and treatment with application of mineral fertilizers NPK (average yearly dose of P 64.2 kg/ha) after three year experiment.

The smallest differences among bioavailable P content after 18 years (except treatment SS 1 at site Lukavec) were found at site Suchdol. It was caused due to the high P soil sorption capacity. The value of P soil sorption capacity is affected with the soil reaction (Table 1) and 4% carbonates content at Suchdol site (Kodešová *et al.* 2016). The amount of bioavailable P depends on soil P sorption. The soil with low P sorption capacity tends to have higher content of bioavailable P and conversely (Djodic & Mattson 2013).

Figure 1 shows the available P content (after 18 years) and its statistical evaluation at Červený Újezd, Lukavec and Suchdol site, respectively. Significant differences between available phosphorus contents were found at the treatment SS 3, all mineral fertilizing treatments (N, N + straw, NPK) and control treatment, respectively. Antoniadis *et al.* (2015) published significantly higher content of bioavailable P between treatment with high dose 60 t/ha of sewage sludge (dose of P 147 kg/ha) and mineral NPK treatment with dose of P 24.5 kg/ha (in form triple superphosphate) after two years, but significant difference between 20 t/ha (dose of P 49 kg/ha) and 40 t/ha (dose of P 98 kg/ha) of sewage sludge was not found.

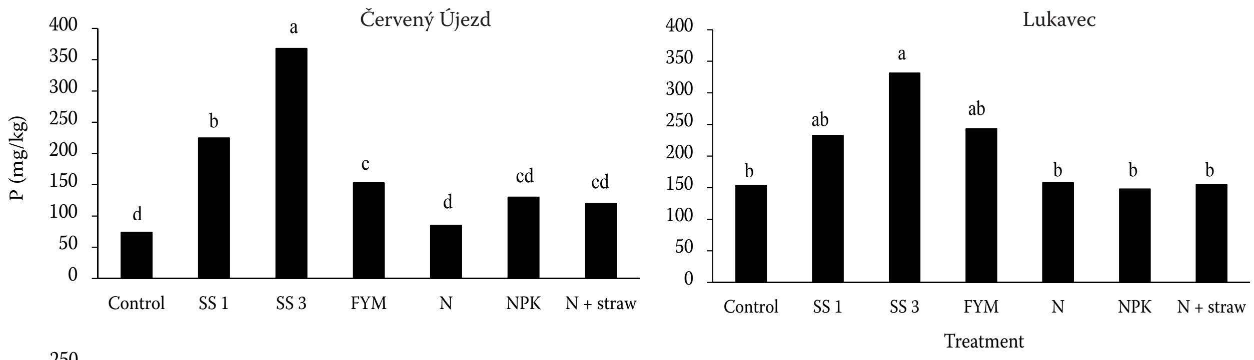
SS 1 treatment had significantly higher available P content in comparison to mineral treatments and control treatment at Červený Újezd and Suchdol sites. FYM treatment showed significantly higher available P contents in comparison to N and control treatment at Červený Újezd site. For other cases, statistically significant differences were not found.

Table 4 Available phosphorus content changes (Δmg/kg) after 18 years of experiments

	Control	SS	SS 3	FYM	N	N + straw	NPK
Č. Újezd	–45	107	258	37	–57	–54	–36
Lukavec	–44	40	135	56	–44	–42	–56
Suchdol	–3	83	123	18	–22	–11	–8

SS, SS 3 – sewage sludge; FYM – farmyard manure

https://doi.org/10.17221/175/2018-SWR



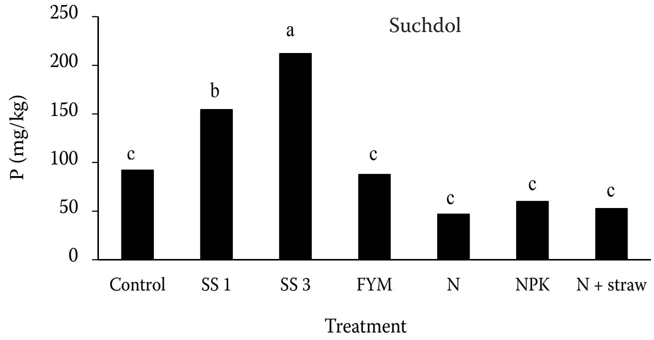


Figure 1. The available P contents in soil after 18 years of fertilizing

Different letters within a column indicate a significant difference at $P \leq 0.05$; SS1, SS 3 – sewage sludge; FYM – farmyard manure

CONCLUSION

Reffering to stated results it is evident that long-term fertilization influences the content of bioavailable phosphorus in soil. Application of farmyard manure and sewage sludge significantly increased available P content in soil. On the contrary, mineral fertilization led to the decrease of available P content in soil including yearly application of phosphorus (30 kg P/ha/year). For the precise evaluation of available phosphorus changes, its relations to soil conditions and grown plants must be taken into account.

References

Antoniadis V., Koutroubas S.D., Fotiadis S. (2015): Nitrogen, phosphorus, and potassium availability in manure-and sewage sludge-applied soil. Communications in Soil Science and Plant Analysis, 46: 393–404.

Arvas O., Celebi S.Z., Yilmaz I.H. (2011): Effect of sewage sludge and synthetic fertilizer on pH, available N and P in pasture soils in semi-arid area, Turkey. African Journal of Biotechnology, 10: 16508–16515.

Černý J., Balík J., Kulhánek M., Čásová K., Nedvěd V. (2010): Mineral and organic fertilization efficiency in long-term stationary experiments. Plant, Soil and Environment, 56: 28–36.

Djodic F., Matsson L. (2013): Changes in plant-available and easily soluble phosphorus within 1 year after P amendment. Soil Use Management, 29: 45–54.

Du Z.Y., Wang Q.H., Liu F.C., Ma H.L., Ma B.Y., Malhi S.S. (2013): Movement of phosphorus in a calcareous soil as affected by humic acid. Pedosphere, 23: 229–235.

Eghball B. (2002): Soil properties as influenced by phosphorus- and nitrogen-based manure and compost applications. Agronomy Journal, 94: 128–135.

Gu X., Wang L., Wang L., Fan Y., Yang H., Long H. (2016): Monitoring available phosphorus content in soil of cultivated land based on hyperspectral technology. In: Geoscience and Remote Sensing Symposium (IGARSS), IEEE International, July 10–15, 2016, Bejing: 6393–6396.

Káš M., Mühlbachová G., Kusá H., Pechová M. (2016): Soil phosphorus and potassium availability in long-term field experiments with organic and mineral fertilization. Plant, Soil and Environment, 62: 558–565.

Kobza J., Gáborík Š. (2008): Current State and Development of Macro- and Micronutrients in Agricultural Soils of Slovakia. Bratislava, SSCRI (VÚPOP) Bratislava. (in Slovak)

Kobza J., Barančíková G., Bezák P., Dodok R., Grečo V., Hrivňáková K., Chlpík J., Lištjak M., Makovníková J., Mališ J., Píš V., Schlosserová J., Slávik O., Styk J., Širáň M. (2011): Uniform Analytical Procedures in Soil. Bratislava, SSCRI (VÚPOP) Bratislava. (in Slovak)

Kodešová R., Kočárek M., Klement A., Golovko O., Koba O., Fér M., Nikodém A., Vondráčková L., Jakšík O., Grabic R. (2016): An analysis of the dissipation of pharmaceuticals under thirteen different soil conditions. Science of the Total Environment, 544: 369–381.

Kondratowicz-Maciejewska K., Kobierski M. (2011): Content of available magnesium, phosphorus and potassium

https://doi.org/10.17221/175/2018-SWR

forms in soil exposed to varied crop rotation and fertilisation. Journal of Elementology, 16: 543–553.

Kruse J., Abraham M., Amelung W., Baum C., Bol R., Kuhn O., Lewandowski H., Niederberger J., Oelmann Y., Ruger C., Santner J., Siebers M., Siebers N., Spohn M., Vestergren J., Vogts A., Leinweber P. (2015): Innovative methods in soil phosphorus research: A review. Journal of Plant Nutrition and Soil Science, 178: 43–88.

Kulhánek M., Balík J., Černý J., Vaněk V. (2009): Evaluation of phosphorus mobility in soil using different extraction methods. Plant, Soil and Environment, 55: 267–272.

Lindsay W.L. (1979): Chemical Equilibria in Soils. New York, John Wiley and Sons Inc.

Liu E.K., Yan C.R., Mei X.R., He W.Q., Bing S.H., Ding L.P., Liu Q., Liu S.A., Fan T.L. (2010): Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. Geoderma, 158: 173–180.

Mehlich A. (1984): Mehlich-3 soil test extractant – a modification of Mehlich-2 extractant. Communications in Soil Science and Plant Analysis, 15: 1409–1416.

Mikulášová B., Lapčík L., Mašek I. (1997): Lignite: Structure, properties and applications. Chemické Listy, 91: 160–168.

Mohanty S., Paikaray N.K., Rajan A.R. (2006): Availability and uptake phosphorus from organic manures in groundnut (*Arachis hypogea* L.) and corn (*Zea mays* L.) sequence using radio tracer technique. Geoderma, 133: 225–230.

Nest T.V., Vandecasteele B., Ruysschaert G., Cougnon M., Merckx R., Reheul D. (2014): Effect of organic and mineral fertilizers on soil P and C levels, crop yield and P leaching in a long-term trial on a silt loam soil. Agriculture, Ecosystems and Environment, 197: 309–317.

Nogueirol R.C., Melo W.J., Bertoncini E.I., Alleoni L.R.F. (2015): Effectiveness of extractants for bioavailable phosphorus in tropical soils amended with sewage sludge. Applied and Environmental Soil Science, 2015: 720167.

Pierzynski G.M., Vance G.F., Sims J.T. (2005): Soils and Environmental Quality. 3rd Ed. Boca Raton, CRC Press.

Schroder J.L., Zhang H.L., Richards J.R., Payton M.E. (2009): Interlaboratory validation of the Mehlich 3 method as a universal extractant for plant nutrients. Journal of AOAC International, 92: 995–1008.

Skwierawska M., Zawartka L., Zawadzki B. (2008): The effect of different rates and forms of sulphur applied on changes of soil agrochemical properties. Plant, Soil and Environment, 54: 171–177.

Sommers L.E. (1977): Chemical composition of sewage sludges and analysis of their potential use as fertilizers. Journal of Environmental Quality, 6: 225–232.

Souza R.F., Faquin V., Lima Sobrinho R.R., Oliveira E.A.B. (2010): Liming and organic fertilizer: influence on phosphorus adsorption in soils. Revista Brasiliera de Ciencia do Solo, 34: 143–150.

Troeh R.F., Thompson L.M. (2005): Soils and Soil Fertility. 6th Ed. Ames, Blackwell Publishing.

Wu L.H., Cheng M.M., Li Z., Ren J., Shen L.B., Wang S.F., Luo Y.M., Christie P. (2012): Major nutrients, heavy metals and PBDEs in soils after long-term sewage sludge application. Journal of Soils and Sediments, 12: 531–541.

WRB (2015): World Reference Base for Soil Resources 2014: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Rome, FAO.

Zamuner E.C., Picone L.I., Echeverria H.E. (2006): Comparison of phosphorus fertilization diagnostic methods for wheat under no-tillage. Soil and Tillage Research, 89: 70–77.

Zbíral J., Němec P. (2002): Comparison of Mehlich 2, Mehlich 3, CAL, Egner, Olsen, and 0.01 M $CaCl_2$ extractants for determination of phosphorus in soils. Communications in Soil Science and Plant Analysis, 33: 3405–3417.

Zhang H.L., Kariuki S., Schroder J.L., Payton M.E., Focht C. (2009): Interlaboratory validation of the Mehlich 3 method for extraction of plant-available phosphorus. Journal of AOAC International, 92: 91–102.

Received for publication September 5, 2018
Accepted after corrections November 22, 2018
Published online March 29, 2019