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Soil pH Changes in Long-Term Field Experiments with Different Fertilizing Systems

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Abstract

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The changes of soil pH in long-term 14-year field experiments with different fertilizing systems are described. The field experiments were located at four sites of the Czech Republic with different soil and climatic conditions (Červený Újezd, Hněvčeves, Lukavec, and Prague-Suchdol). At each site, the same fertilizing systems and crop rotation (potatoes – winter wheat – spring barley) were established. Six experimental treatments were applied to crop rotation: (1) unfertilized treatments (control); treatments with organic fertilization: (2) farmyard manure (FYM), (3) sewage sludge (SS); treatments with mineral fertilizers: (4) nitrogen (N), (5) nitrogen with straw application (N + straw), and (6) nitrogen with phosphorus and potassium (NPK). The long-term effect of fertilizers significantly depends on soil conditions. At the site Prague-Suchdol minimal differences in the soil pH were observed by all treatments. This is caused by the high buffering capacity of Chernozems against the soil acidification. At Červený Újezd (Haplic Luvisol), Hněvčeves (Haplic Luvisol), and Lukavec (Stagnic Cambisol) sites, soil pH decreased by all treatments. Only at Hněvčeves site the soil pH did not change with N treatment. The highest soil pH decrease in the treatment with NPK (ΔpH –0.89) and N + straw (ΔpH –0.70) was observed at Hněvčeves site. By the treatments FYM and SS the highest decrease was registered at Červený Újezd (ΔpH of about –0.30 and –0.63, respectively). The highest decrease in control treatment (ΔpH of about –0.63) was observed at Lukavec site. The results showed that to evaluate long-term soil pH changes a whole complex of factors must be examined.

Keywords: acidification; crop rotation; mineral fertilization; organic fertilization; soil type

Soil pH is widely accepted as a dominant factor that regulates soil nutrient bioavailability, vegetation community structure, plant primary productivity, and a range of soil processes including soil microbial community structure and activity (Robson 1989). All the soil properties and the value of the soil pH can widely differ in reliance on soil type, topography, climate, vegetation, and anthropogenic activity, because all these factors influence the spatial variability of the observed soil types (Shi *et al*. 2009). The value of soil pH is directly influenced by all five soil-forming factors (parent rock, climatic conditions, organisms, topography, and time) and further the value of soil pH is dependent on the season influence, way of management, tested soil horizon, soil water contents, and time limit of sampling for analysis (Troeh & Thompson 2005).

The combined application of manure and mineral fertilizer has major effects on soil physical, chemical, and biological properties and it increases crop yields (Hou *et al*. 2012). Application of fertilizers is one of the causes of soil acidification (Hoyt & Hennig 1982). The acidification of soil by N fertilizer is caused by transformation of nitrogen in soil. The uptake of N as ammonium in the crop also contributes to soil acidification (Malhi *et al*. 1998).

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Farmyard manure (FYM) is the main fertilizer maintaining soil potential fertility because with its application the soil receives biogenic elements that are assimilated by growing crops and thus removed from the soil (Repsiene & Skuodiene 2010). The manure application increases also soil pH (Ondrášek & Čunderlík 2008). Increasing of pH depends on the dose and timing of FYM application. Leahu *et al*. (2011) found during the experiment that the soil pH decreased for both versions: the control variant and the variants fertilized only with mineral fertilizers or using both mineral fertilizers and manure.

The aim of the study is to compare the change in the soil pH between treatments with mineral, organic fertilizers and unfertilized treatments applied during 14-years of experiments.

MATERIAL AND METHODS

Changes in the values of the soil reaction in the course of long-term field experiments at four sites – Červený Újezd, Prague-Suchdol, Hněvčeves, and Lukavec with different soil and climatic characteristics were monitored. Climatic and soil conditions are showed in Table 1. Contents of plant available nutrients in soil were published by Černý *et al*. (2010).

The same fertilizing systems with organic, mineral, and unfertilized control treatments are used at all sites. Potatoes, winter wheat, and spring barley are grown in crop rotation. Only at Červený Újezd silage maize is included to the crop rotation instead of potatoes because of agronomical conditions of the experimental site. Organic fertilizer (silage maize) is applied each autumn before planting the potatoes. Nitrogen is applied in the form of calcium ammonium nitrate. The area of the experimental plots at Hněvčeves and Lukavec is the same – 60 m^2, at Suchdol the area of the plot is 60.5 m^2, and at Červený Újezd it is 80 m^2. At all the sites crops are rotated in the sequence potatoes – winter wheat – spring barley. Fertilizing system and doses of nutrients during crop rotation are shown in Table 2.

Soil pH values were determined from the composite soil samples taken at establishment experiments before the first application of fertilizer in 1996. Soil pH was measured after the end of the crops rotation (i.e. after spring barley) in the years 2004 and 2010. Soil pH value of 2004 corresponds with the changes between 1996 and 2010 and therefore samples from 2001 and 2007 were not evaluated. The composite soil sample consisted of ten subsamples collected throughout the plot to the depth of 30 cm. Soil samples were oven-dried at the constant temperature of 30°C. Dry soil samples were sieved through a 2-mm mesh. Soil pH was determined in 0.2 mol/l KCl 2:5 w/v according to the methodology of the Central Institute for Supervising and Testing in Agriculture (Zbíral 2001). Each sample was measured four times. The soil reaction was measured using a pH meter WTW pH340i and a glass electrode WTW SenTix 21 (both devices WTW, Weilheim, Germany).

Table 1. Soil and climatic conditions

Sites	Červený Újezd	Hněvčeves	Lukavec	Prague-Suchdol
Location	50°4'22"N, 14°10'19"E	50°18'46"N, 15°43'3"E	49°33'23"N, 14°58'39"E	50°7'40"N, 14°22'33"E
Elevation (m)	398	265	610	286
Average annual temperature (°C)	7.7	8.2	7.7	9.1
Average annual rainfall (mm)	493	573	666	495
Soil type (WRB 2006)	Haplic Luvisol	Haplic Luvisol	Stagnic Cambisol	Haplic Chernozem
NRSC USDA	silty loam	silty loam	sandy loam	silty loam
CEC (mmol(+)/kg)	145	179	128	230
C_{ox} (%)	1.17	1.06	1.27	1.55
Clay (%) (< 0.002 mm)	5.4	4.4	3.2	2.2
Silt (%) (0.002–0.05 mm)	68.1	77.0	37.1	71.8
Sand (%) (0.05–2 mm)	26.5	18.7	59.7	26.0

CEC – cation exchange capacity

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Table 2. Doses of nutrients during crop rotation (kg/ha)

Treatment	Potatoes/maize			Wheat			Barley		
	N	P	K	N	P	K	N	P	K
Control	–	–	–	–	–	–	–	–	–
SS	330[1]	201[2]	55[2]	0	0	0	0	0	0
FYM	330[1]	118[2]	374[2]	0	0	0	0	0	0
N	120	0	0	140	0	0	70	0	0
NPK	120	30	100	140	30	100	70	30	100
N + straw	138	6[2]	47[2]	140	0	0	70	0	0

[1]total nitrogen in organic fertilizers; [2]average dose of the fertilizers nutrient contents; SS – sewage sludge; FYM – farmyard manure; NPK – nitrogen with phosphorus and potassium

RESULTS AND DISCUSSION

The measured pH values of 1996 and 2004 from all experimental sites are presented in Table 3. Figure 1 shows minimal changes in soil pH of Chernozem at the site Prague-Suchdol. The minimal changes in all variants are caused by the higher buffering capacity against soil acidification. The same result was published by Yang *et al.* (2007). In his 22-year field experiment with mineral and organic fertilizers in soil with high carbonate content no change in the soil pH was observed.

In the control unfertilized treatments there was a decrease in the soil pH at all experimental sites (Table 4). The biggest decrease was ascertained at Lukavec, which is probably caused by lighter soil and lower sorption capacity. The decrease in pH is likely caused by leaching of basic ions and removal of basic ions by plants. For Ca and Mg leaching the annual rainfall is important. Lysimeter experiments conducted in the Czech Republic indicated that the annual rainfall higher than 600 mm may lead to calcium loss of about 27 kg/ha per year (Klement & Prchalová 2013). Lowering of pH in the control unfertilized treatment after a one-year observation was also documented by Arvas *et al.* (2011).

In the same study, pH reduction in treatments with sewage sludge application was traced after a one-year observation (Arvas *et al.* 2011). A slight reduction in pH was observed also by Tsadilas and Samaras (1999) after two years of experiments with sewage sludge applications. Forsberg and Ledin (2005) explain the pH decrease after the application of the sewage sludge by the buffering capacity reduction. The pH decrease magnitudes depend on the sludge application dose (Navas *et al.* 1998). This corresponds with the observed decreases of soil pH at the sites Červený Újezd, Hněvčeves, and Lukavec (Table 4).

At the present long-term field experiment the stabilizing effect of FYM on soil pH was not proved and after 14-years of FYM application pH decreased at all the sites (Table 4). The largest decrease was observed at Červený Újezd. However, the soil treated for 14 years with FYM exhibited higher pH than that treated with NPK at all the sites and with N at the sites Červený Újezd, Hněvčeves, and Lukavec. The lower soil pH decrease in treatments where organic fertilizers instead of mineral were applied is caused by the incorporation of organic matter in the soil minimizing pH fluctuation, which is consistent with the results of the 21-year-old experiment by Zhong *et al.* (2010). Bednarek *et al.* (2012), after 26 years of experiments, found higher pH and higher organic matter content by the soils with manure application

Table 3. Soil pH values detected at the time of setting up the experiment (1996) and in 2004

Treatments	Červený Újezd		Hněvčeves		Lukavec		Praha-Suchdol	
	1996	2004	1996	2004	1996	2004	1996	2004
Control	6.19	6.09	5.99	6.00	5.37	4.87	7.13	6.97
SS	6.73	6.29	6.16	5.98	5.09	5.02	7.26	7.21
FYM	6.54	6.37	6.17	6.04	5.25	4.89	7.29	7.26
N	6.41	6.34	5.77	5.83	4.98	4.67	7.21	7.29
NPK	6.66	6.44	6.31	6.07	5.29	4.71	7.27	7.31
N + straw	6.87	6.70	6.20	6.08	5.22	4.86	7.30	7.33

SS – sewage sludge; FYM – farmyard manure; NPK – nitrogen with phosphorus and potassium

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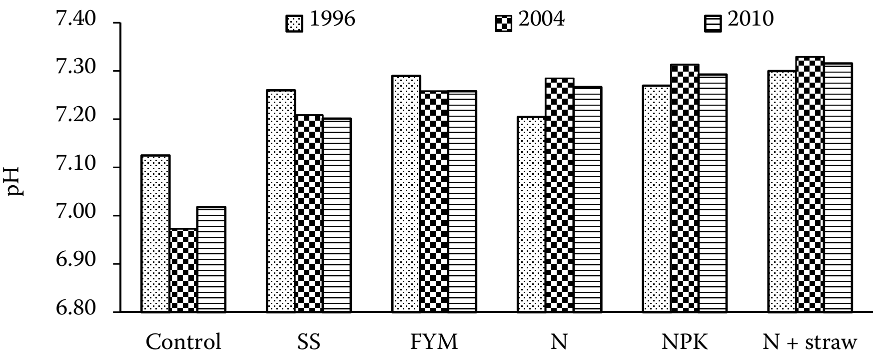

Figure 1. Soil pH_{KCl} at site Prague-Suchdol; SS – sewage sludge; FYM – farmyard manure; NPK – nitrogen with phosphorus and potassium

compared to those where mineral fertilizers (NPK) were applied.

Nitrogen fertilizers generally caused soil acidification. Irrespective of whether the NH_4^+-N is from ammonium nitrate, urea or anhydrous ammonia, the formed nitrate requires the same amount of compensating cations per unit of N applied. This requirement is theoretically 1.36 kg Ca/kg N (Gasser 1973). Practically Sluijsman (1970) calculated the acidity of nitrogen fertilizers separately for arable land and permanent grassland. The calculation includes only half the amount of nitrogen applied (50% utilization of N). Except for Lukavec, showing a quite significant pH reduction, no declines were recorded at the remaining sites (Table 4). This is probably caused by lower acidity of the nitrogen fertilizer with calcium. As for the nitrogen fertilizer acidity degree, Peryea and Burrows (1999) stated that ammonium nitrogen fertilizers containing calcium are among those causing the lowest acidification.

In the variant with the application of NPK, after 14 years of the experiments, there was a decrease in pH at all studied sites (Table 4) except for Prague-Suchdol. The highest decrease occurred at Hněvčeves. The soil acidification after the application of NPK corresponds with the results published by Makinde *et al.* (2009) who described the acidification after the application of NPK in Orthic Luvisol. The decrease in pH of 0.28 after the application dose of 300 kg NPK 15/15/15 on Luvisol was also published by Ayeni *et al.* (2012). Soil pH values during the experiment were also influenced by lowering sulphur deposition in the soil due to flue gas desulfurization in industry reducing the acidifying effect (Balík *et al.* 2009).

At Červený Újezd, Hněvčeves, and Lukavec sites, where nitrogen with straw was applied, the soil pH decreased (Table 4), which corresponds with the results stemming from the 27 long-term field experiments with ploughed straw with doses variants of 0, 25, 50, 75 kg N/ha/year. Soil pH decreased in all the variants, even in the variant with only ploughed straw (Malhi *et al.* 2011).

CONCLUSION

From the stated results it is evident that the evaluation of changes in soil pH must be assessed in relation to specific sites conditions. Chernozem at Prague-Suchdol site showed higher buffering capacity against acidification. The NPK treatment at Červený Újezd, Hněvčeves, and Lukavec sites caused higher soil pH decrease compared with the control treatment. The FYM treatment at the same sites led to lower soil pH decreases (or the N treatment at Hněvčeves) than the other treatments except for those with N. Mineral and organic fertilization proved to be one of the factors causing soil acidification.

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Table 4. Soil pH changes (ΔpH) after 14 years of experiments (1996–2010)

	Control	SS	FYM	N	NPK	N + straw
Červený Újezd	–0.38	–0.63	–0.30	–0.22	–0.46	–0.30
Hněvčeves	–0.25	–0.56	–0.21	0.03	–0.89	–0.70
Lukavec	–0.63	–0.22	–0.21	–0.46	–0.71	–0.40
Suchdol	–0.11	–0.06	–0.03	0.06	0.02	0.02

SS – sewage sludge; FYM – farmyard manure; NPK – nitrogen with phosphorus and potassium

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