

Evaluating of phosphorus quantity/intensity parameters in soil with different systems of organic fertilising

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ABSTRACT

One of the refinement methods for estimating the parameters of phosphorus dynamics in soil is the construction of sorption isotherms in dependence on changes of exchangeable sorbed phosphorus in soil (ΔQ) and changes of phosphorus amount in soil solution (ΔI). Regression analysis allows to calculate equilibrium concentration (c_{equ}) and phosphorus buffering capacity (BC). The mentioned analyses were realised on soils from the long-term field experiments of the Czech University of Life Sciences (CULS) in Prague and Crop Research Institute (CRI) in Ruzyně, Czech Republic. The influence of different organic fertilisers compared to the control (not amended) treatment was tested. For the evaluating of parameters, the root and logarithmic functions were used. The lowest c_{equ} of the logarithmic function was always found on not amended treatment. Low amounts were found in the treatments amended with barley straw as well. The highest amounts were found in soil after potatoes cropping fertilised with farmyard manure (FYM). In the FYM variant fertilised with 70 kg P/ha, the c_{equ} value reached 0.45 mg P/l. Both treatments fertilised with sewage sludge (720 kg P/ha and 240 kg P/ha) showed similar values of about 0.25 mg P/l. A different trend was found for the phosphorus buffering capacity (BC); this was the highest at the control treatment and at the treatment fertilised with straw. The lowest BC was observed in both soils after potatoes fertilised with FYM, where it reached 61 mg P/kg and 65 mg P/kg, respectively. Similar trends were found when evaluating root function.

Keywords: long-term experiments; soil; phosphorus dynamics; equilibrium concentration; buffering capacity

Currently, supplemental parameters for estimating phosphorus in soils obtained with static and kinetic methods are often used (Macháček 1999). Evaluating phosphorus dynamics in soils is important for obtaining deeper insight into phosphorus transformations in soils in dependence on their properties. Different methods can be used for a long-term characterisation of phosphates releasing processes from soil matrix to the soil solution (McGeachan 2002). Evaluating dynamic indices is an ideal variant for estimating fertiliser amounts needed (e.g. sewage sludge) (Barry et al. 1995).

For the realization of these methods we start from several basic parameters: intensity – I – level of instantaneous phosphorus availability to the plants. Extraction with 0.01M CaCl_2 or solution of other weak salts are most commonly used. Furthermore, electroultrafiltration is sometimes

used (Self-Davis et al. 2000). The intensity can be only calculated on the basis of the phosphorus buffering capacity (BC).

The phosphorus buffering capacity is also termed differential, phosphate and equilibrium capacity. It can be defined as the capability of a soil to compensate concentration changes of different phosphorus forms (Hartikainen 1991). These data are commonly used to evaluate phosphorus amount that is desorbed by dilution of solution, but not phosphate, which is bound through slow and strong sorption (McGeachan and Lewis 2002). Total BC is calculated from adsorption-desorption dependence as a portion of change of quantity (ΔQ) and intensity (ΔI). The advantage when using these relations is that it is possible to predict the sorption and mobilisation of phosphorus in soils (Morel et al. 1996) and to more accurately

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evaluate phosphorus availability in soils in comparison with other methods estimating available phosphorus (Hartikainen 1991).

The most commonly used methods for evaluating phosphorus dynamics in soils are the adsorption-desorption isotherms (Fox and Kramparth 1970). They are usually used to correct obtained data on adsorption of phosphorus and other reactive solutions. Some formulas are calculated with nonlinear relations (Chien and Clayton 1980, McGechan and Lewis 2002, Eckholm et al. 2005). They are defining an immediate effort to reach equilibrium in their simplest form, but they can be modified to describe the time dependent approximation of equilibrium.

MATERIAL AND METHODS

The long-term field experiment was based on experimental fields of CULS and CRI in Prague-Ruzyně, Czech Republic. The characteristic of the sites is given in Table 1.

Potatoes (cv. Karin), winter wheat (cv. Samanta) and spring barley (cv. Akcent) were cropped in crop rotation on small plots (60 m²). Maize (hybrid Rivaldo) was cropped instead of potatoes on the site Červený Újezd. Organic fertilisers were applied only to the first crop in crop rotation. Because

of that, the direct influence of organic fertilisers application could be observed on potatoes and maize. On winter wheat and spring barley it was possible to observe the consequential influence. The amounts of phosphorus in different treatments are summarised in Table 2. For this experiment, sewage sludge from wastewater treatment plant in Prague was used. Barley straw is always ploughed in before potatoes and maize cropping.

The whole system of fertilising is based on the uniform ratio of 330 kg N/ha per 3 years. That applies for organic and mineral fertilisers or their combinations. Only to the sludge 3 treatment 990 kg N/ha per 3 years was added in the form of sewage sludge.

The modified methodology of Self-Davis et al. (2000) was used for the analysis. The stock solution consisted of 0.01M CaCl₂. Different amounts of phosphorus in the form of KH₂PO₄ were added to the solution so that the resulting gradient of extractants had a phosphorus concentration of 0, 1, 2, 3, 4, 6, 8, 10 mg P/l. Five g of the sample was used for the extraction. An amount of 50 ml of the extraction solution was added to each sample. Each sample was also extracted with all of the mentioned phosphorus concentrations. After 120 min of shaking the samples were filtered and the content of phosphorus was measured spectrophotometrically using the SKALAR SAN^{PLUS} SYSTEM.

Table 1. Characteristic of experimental fields

| Site | Altitude (m) | Mean yearly | | Soil type | Soil sort | pH (CaCl ₂) |
|---------------|--------------|---------------|------------------|-----------|------------|-------------------------|
| | | rainfall (mm) | temperature (°C) | | | |
| Červený Újezd | 410 | 493 | 7.7 | luvisol | loam | 6.5 |
| Hněvčeves | 265 | 573 | 8.2 | luvisol | silty loam | 5.9 |
| Humpolec | 525 | 665 | 7.0 | cambisol | sandy loam | 5.1 |
| Lukavec | 610 | 666 | 7.7 | cambisol | sandy loam | 5.3 |

Table 2. System of fertilising of the long-term field experiment (amount of added nutrients per ha)

| Treatment | Potatoes | Winter wheat | Spring barley |
|------------------|--------------------------------|--------------|---------------|
| Control | 0 | 0 | 0 |
| Sludge 1 | 330 kg N, 240 kg P | 0 | 0 |
| Sludge 3 | 990 kg N, 720 kg P | 0 | 0 |
| FYM 1 | 330 kg N, 70 kg P | 0 | 0 |
| FYM ½ | 165 kg N, 35 kg P | 110 kg N* | 55 kg N* |
| Barley straw + N | 120 kg N* + 5 t straw (4 kg P) | 140 kg N* | 70 kg N* |

*nitrogen was added in the mineral fertilizer CAN 27% N

RESULTS AND DISCUSSION

An increasing trend with a higher amount of phosphorus added in organic fertilisers was found when evaluating phosphorus intensity in soil solution estimated with 0.01M CaCl_2 . The average amount of phosphorus in the soil solution at the control treatment was only 0.09 mg P/l while at the sludge 3 treatment 0.2 mg P/l. Almost the same results as at the control treatment were reached at both treatments fertilised with farmyard manure, where the content ranged about 0.17 mg P/l. Similar results at the treatments fertilised with farmyard manure were reached in the work by Kulhánek et al. (2007), where the concentrations of phosphorus in soil was 1.4 mg P/l, which results in an intensity of 0.14 mg P/l.

For the construction of sorption isotherms the amount of phosphorus bounded on hard phase of soil Q (mg P/kg) was used. It was calculated as a difference between the amount of added phosphorus and the amount of phosphorus measured in the extract. Two basic functions were used for the formation of sorption isotherms. One of them was the root function (1) and the second logarithmic regression (2):

$$\Delta Q = a\sqrt{\Delta I} + b \quad (1)$$

$$\Delta Q = a\ln(\Delta I) + b \quad (2)$$

The high coefficients of determination R^2 were reached for both of them. That shows a very close relationship between ΔQ and ΔI . This relationship was described in many works (Fox and Kramparth 1970, Barrow 1983, Okajima et al. 1983). McGeachan and Lewis (2002) described usage of the logarithmic function while Schweitzer et al. (2005) used the root function.

Parameters a and b were calculated from the form of the isotherms. Then, the equilibrium capacity c_{equ} was calculated, when ΔQ reached 0. The c_{equ} value is also the intensity of phosphorus in soil solution, where the equilibrium between soil solution and exchangeable sorbed phosphorus is reached. Then, the phosphorus buffering capacity was calculated. That means the possibility of soil to equalise the changes of phosphorus concentrations in soil solution. BC was calculated as a portion of a/c_{equ} . The results are summarised in Table 3.

From Table 3 is clear that the lowest c_{equ} after harvest of all crops was calculated in the soil at the control treatment. In the soil after the harvest of potatoes the concentration of phosphorus was

estimated at 0.16 mg P/l, after wheat 0.11 mg P/l and after barley 0.20 mg P/l. Low contents were also found in the treatment fertilised with barley straw (5 kg P/ha added). Here the values ranged from 0.20 to 0.23 mg P/l. The obtained results suggest that in nonfertilised treatments and treatments fertilised with low amounts of phosphorus at equilibrium, phosphorus concentration in soil solution is low. It means, that only a low amount of phosphorus is plant-available.

Interesting results were obtained at the treatments fertilised with sewage sludge. Great differences were found especially in samples after the harvest of potatoes. In both treatments fertilised with sewage sludge lower values of c_{equ} were obtained, compared to the treatments fertilised with farmyard manure. At the sludge 3 treatment (720 kg P/ha) the c_{equ} was 0.28 mg P/l and only 0.26 mg P/l at the sludge 1 treatment (240 kg P/ha). Thus, at the FYM 1 treatment (70 kg P/ha) the c_{equ} was 0.45 mg P/l and at the FYM ½ treatment (35 kg P/ha) 0.39 mg P/l. Therefore, sewage sludge is a smaller source of readily available phosphorus in comparison with farmyard manure. One of the possible explanations is that with the application of sewage sludge into the soil, high amounts of Fe and Al oxides are added. These oxides are adsorbing phosphorus leading to the non-available form. Soil solution also contained lower amounts of readily available phosphorus. The same results were obtained by McDowell et al. (2003).

The highest phosphorus buffering capacity (BC) was always measured at the control treatments. Therefore, nonfertilised soils have the highest ability to sorb phosphorus added to soil. Phosphorus concentrations reached 133 mg P/kg in soil after potatoes cropping, 132 mg P/kg after wheat and 167 mg P/kg after barley. High values were calculated at the treatments fertilised with barley straw (5 kg P/ha) as well. Here, almost the same results were obtained at all treatments. The values ranged from 110 to 113 mg P/kg.

With increasing equilibrium of phosphorus concentration the BC decreased. The lowest BC was obtained in soils after the harvest of potatoes fertilised with farmyard manure. At the FYM 1 treatment amended with 70 mg P/kg the BC was 61 mg P/kg and at the FYM ½ treatment fertilised with 35 kg P/ha the BC was 65 mg P/kg. Compared to the control treatment, the application of sewage sludge resulted in lower BC values, but compared to the FYM treatments the BC was significantly higher. Comparable results were obtained by Anderson and Wu (2001). They compared the

Table 3. Characteristics of sorption parameters estimated with the logarithmic function

| Crop | Treatment | <i>a</i> | <i>b</i> | <i>R</i> ² | <i>c</i> _{equ} (mg P/l) | BC (mg P/kg) |
|---------------------|-----------|----------|----------|-----------------------|----------------------------------|--------------|
| Potatoes (maize) | control | 20.85 | 38.62 | 0.96 | 0.16 | 133 |
| | sludge 1 | 24.68 | 34.22 | 0.98 | 0.25 | 99 |
| | sludge 3 | 25.05 | 31.74 | 0.95 | 0.28 | 89 |
| | FYM 1 | 27.71 | 22.02 | 0.97 | 0.45 | 61 |
| | FYM ½ | 25.58 | 23.84 | 0.95 | 0.39 | 65 |
| | straw + N | 22.41 | 35.63 | 0.96 | 0.20 | 110 |
| Wheat | control | 18.69 | 41.50 | 0.97 | 0.11 | 172 |
| | sludge 1 | 21.69 | 39.49 | 0.97 | 0.16 | 134 |
| | sludge 3 | 22.65 | 36.77 | 0.96 | 0.20 | 115 |
| | FYM 1 | 23.14 | 36.29 | 0.97 | 0.21 | 111 |
| | FYM ½ | 22.32 | 35.47 | 0.96 | 0.20 | 109 |
| | straw + N | 22.55 | 35.73 | 0.96 | 0.21 | 110 |
| Barley | control | 19.87 | 42.25 | 0.97 | 0.20 | 167 |
| | sludge 1 | 20.96 | 32.10 | 0.95 | 0.22 | 97 |
| | sludge 3 | 28.29 | 25.66 | 0.98 | 0.40 | 70 |
| | FYM 1 | 23.12 | 33.19 | 0.97 | 0.24 | 97 |
| | FYM ½ | 21.88 | 32.47 | 0.95 | 0.23 | 97 |
| | straw + N | 22.01 | 36.03 | 0.96 | 0.20 | 113 |

*c*_{equ} – equilibrium concentration; BC – phosphorus buffering capacity

influence of fertilising with pig and cattle slurry on the BC. With increasing ratio of fertilisers they also obtained decreasing BC.

When observing the subsequent influence of organic fertilisers to other crops the differences between the sewage sludge and farmyard manure were almost identical. The lowest differences were obtained after the harvest of wheat where the BC values ranged between 109 and 134 mg P/kg. The low differences were also calculated in the soil after the harvest of barley, where the same BC of 97 mg P/kg at the sludge 1, FYM 1 and FYM ½ treatments were found.

The root function was relatively low and accurate. Lower coefficients of determinance *R*² were calculated; however, the greatest disadvantage of this method was that this function was not accurate especially in the lower parts of the figures. This part is the most important for estimating the equilibrium concentration. The results from the root function are summarised in Table 4.

The trend of evaluating the *c*_{equ} with the root function was very similar with the logarithmic function. The lowest values were also found at the control

treatments. The values calculated were 0.79 mg P/l after the harvest of potatoes, 0.78 mg P/l after wheat and 0.72 mg P/l after barley, which means the values of about 0.5 mg P/l higher than the values computed with the logarithmic function.

At the other treatments the same trend was observed. The highest *c*_{equ} values were obtained in soils after the harvest of potatoes. Here the *c*_{equ} reached 1.24 mg P/l at the FYM 1 treatment fertilised with 70 kg P/ha and 1.19 mg P/l at the half ratio of farmyard manure (FYM ½). In comparison with the sludge 1 (240 kg P/ha) and sludge 3 treatments (720 kg P/ha) the values were higher of about 0.31 mg P/l and 0.25 mg P/l, respectively.

A similar value as at the control treatment was observed in the soil after the harvest of wheat at the sludge 1 treatment. Otherwise, at the other treatments almost the same results between 0.84 and 0.85 mg P/l were obtained.

From the results of soil analysis after the harvest of barley it is clear that the highest *c*_{equ} was at the sludge 3 treatment, where it reached 1.13 mg P/l. There were no significant differences found between other treatments.

Table 4. Characteristics of sorption parameters estimated with the root function

| Crop | Treatment | <i>a</i> | <i>b</i> | <i>R</i> ² | <i>c</i> _{equ} (mg P/l) | BC (mg P/kg) |
|---------------------|-----------|----------|----------|-----------------------|----------------------------------|--------------|
| Potatoes (maize) | control | 22.35 | 5.68 | 0.95 | 0.78 | 29 |
| | sludge 1 | 22.15 | 2.75 | 0.95 | 0.88 | 25 |
| | sludge 3 | 22.65 | 0.20 | 0.97 | 0.99 | 23 |
| | FYM 1 | 19.80 | -4.18 | 0.98 | 1.24 | 16 |
| | FYM ½ | 19.84 | -3.41 | 0.99 | 1.19 | 17 |
| | straw + N | 21.12 | 1.37 | 0.97 | 0.94 | 23 |
| Wheat | control | 27.06 | 6.55 | 0.96 | 0.79 | 34 |
| | sludge 1 | 23.55 | 5.40 | 0.95 | 0.80 | 30 |
| | sludge 3 | 22.72 | 4.00 | 0.95 | 0.84 | 27 |
| | FYM 1 | 22.61 | 3.74 | 0.96 | 0.85 | 27 |
| | FYM ½ | 21.73 | 3.88 | 0.95 | 0.84 | 26 |
| | straw + N | 22.05 | 3.81 | 0.95 | 0.84 | 26 |
| Barley | control | 23.49 | 7.66 | 0.94 | 0.72 | 33 |
| | sludge 1 | 18.99 | 3.76 | 0.95 | 0.82 | 23 |
| | sludge 3 | 21.16 | -2.59 | 0.97 | 1.13 | 19 |
| | FYM 1 | 20.05 | 3.82 | 0.94 | 0.83 | 24 |
| | FYM ½ | 20.69 | 2.20 | 0.97 | 0.90 | 23 |
| | straw + N | 22.16 | 3.89 | 0.96 | 0.84 | 26 |

*c*_{equ} – equilibrium concentration; BC – phosphorus buffering capacity

Compared to the logarithmic function, the obtained BC was significantly lower. With decreasing *c*_{equ} BC increased again. Therefore, the highest values were reached at the control treatment where the BC in the soil after the harvest of potatoes reached 29 mg P/kg, after wheat 34 mg P/kg and after barley 33 mg P/kg.

The lowest BC was obtained in the soils after the harvest of potatoes fertilised with farmyard manure. No significant differences were found between the results after the harvest of wheat. The level of BC in the soils after the harvest of barley was significantly lower only at the treatment sludge 3.

From the results obtained it is clear that using the logarithmic and root function resulted in a similar trend for *c*_{equ} and BC. Due to the form of the isotherms, the logarithmic function seems more suitable.

Farmyard manure used before sowing of potatoes appeared to be the most effective fertiliser from the point of view of *c*_{equ} and BC. Despite of this, the lowest values of *c*_{equ} and the highest values of BC were reached at the treatments fertilised with straw and at the control treatments. In the case of

straw, *c*_{equ} and BC was influenced by the low content of phosphorus that was added to the soil and by biological immobilisation of phosphorus.

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