Environmental Pollution 157 (2009) 2147–2152

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Effect of Polonite used for phosphorus removal from wastewater on soil properties and fertility of a mountain meadow

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Filter substrate Polonite can benefit acid soils after wastewater treatment.

ARTICLE INFO

Article history:
Received 4 December 2008
Received in revised form
4 February 2009
Accepted 8 February 2009

Keywords:
Amendment
Fertilizer
Liming
Polonite
Yield

ABSTRACT

Reactive filter materials used for phosphorus (P) removal from wastewater can be disposed of as soil amendments after treatment, thus recycling P and other macro- and micro-nutrients to plants. In addition, materials with a high pH and Ca content, such as Polonite, are potential soil conditioners, which can be particularly beneficial for acid soils. Polonite previously used for on-site wastewater treatment was applied as a soil amendment to a mountain meadow. The amendment significantly increased soil pH and decreased the hydrolytic acidity, thus reducing Al toxicity risks. The effects were comparable to those of liming. No difference in yield and P uptake by meadow plants was observed. The uptake of metals was lower for amended soils, especially the uptake of Mn. Using Polonite after wastewater treatment as a soil amendment is thus a viable disposal alternative that can replace liming, when necessary, being capable of recycling P and other nutrients to meadow plants.

1. Introduction

Increasing numbers of filter materials have been proposed as suitable media for phosphorus (P) removal in on-site wastewater treatment systems such as constructed wetlands or filter wells (Renman et al., 2004; Hylander et al., 2006; Johansson Westholm, 2006; Shilton et al., 2006). The mechanism of P retention involves sorption reactions and the efficiency depends on the physical and chemical properties of the material. Polonite is a commercial product used as reactive filter media for on-site wastewater treatment in Sweden (Renman, 2008). The material is packed into a filter system (BioP®) that collects and treats wastewater, improving the quality of septic tank effluents, i.e. by reducing the BOD, TSS, FC bacteria, NH_4–N and, particularly, P concentrations. After a certain time, the removal efficiency decreases and the filter substrate must be replaced. The recovered substrate can be disposed of as a soil amendment, thus recycling P and other macro- and micronutrients to plants.

The use of P fertilizers is becoming more expensive and less sustainable because phosphate ores are limited non-renewable resources, a fact that tends to increase the production costs of P derivates (Driver et al., 1999). Recycling Polonite and other filter materials as soil amendments after wastewater treatment may supply nutrients that could complement and reduce the use of mineral P fertilizers. A number of filter materials have already shown fertilizer potential when used as soil amendments in pot cultivation experiments. Ochre, a by-product from iron mining, when saturated with P and used as a slow-release fertilizer, has proven to be as effective as conventional P fertilizer for grass and barley crops (Dobbie et al., 2005). Studies on iron-rich sands and LECA (light expanded clay aggregates) have shown that P sorbed to these substrates is as available as a water-soluble P compound to ryegrass plants (Kvarnström et al., 2004). The industrial by-product, blast furnace slag (BFS) efficiently improved the yield of barley in another study (Hylander et al., 2006). Soil amended with Polonite also improved the yield of barley in that study, and induced an increase in available soil P in another pot experiment (Cucarella et al., 2007). Furthermore, natural calcium-rich materials, such as Polonite, may help improving soil condition and fertility. Industrial by-products with high concentrations of calcium have shown promising results as liming agents while supplying nutrients for plant uptake. Fly ash has been shown to increase soil pH and yield of ryegrass (Matsi and Keramidas, 1999) and grain yield of rice (Mittra et al., 2005) in pot experiments. Blast furnace slag has shown potential benefits as a liming agent (Kühn et al., 2006). Bauxite residue (red mud) improved P uptake by plants in another study

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doi:10.1016/j.envpol.2009.02.007

(Snars et al., 2004). In a recent study, Polonite and Filtra P, the latter a commercial product composed of lime, iron compounds and gypsum, were saturated with artificial P solutions and then used as amendments to an acidic soil. The amendments increased soil pH, P availability measured as AL-extractable P, and the concentration of P in ryegrass plants grown in a pot experiment (Cucarella et al., 2008). The results of that study suggest that recycling Polonite from wastewater treatment filters could be of great benefit for acid soils. However, the use of Polonite as a soil amendment and the effect of such treatment on soil properties need further investigation, particularly under field conditions and in the long term.

The present study investigated the suitability of recycling Polonite from wastewater treatment filters to a mountain meadow by investigating the effects of the amendments on soil properties and fertility. The properties investigated included: (i) soil pH, chemical composition, i.e. total concentrations of elements: P, K, Ca, Mg, Fe, Mn, Zn and Cu, and available forms of P, K and Mg; (ii) soil hydrolytic acidity, i.e. amount of exchangeable acidic cations (H^+ and Al^{3+}), total exchangeable base cations concentrations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and cation exchange capacity; and (iii) yield of meadow plants and total uptake of P, K, Al, Fe, Mn, Zn, Cu and Cr by plants.

2. Materials and methods

2.1. Polonite

Polonite (trade mark Polonite®) is a commercial product used in filter systems for on-site wastewater treatment that can efficiently retain P (Renman et al., 2004; Hylander et al., 2006; Renman, 2008). It is derived from opoka, a bedrock rich in silica and calcium carbonate formed from marine sediments (Brogowski and Renman, 2004). In the manufacturing process, opoka is heated to over 900 °C and most calcium carbonate transforms into calcium oxide. The processing ends by grinding and sieving the material to an appropriate particle size (2–6 mm) that ensures adequate hydraulic conditions in the filter system. Polonite examined in this study was previously used for 28 months in a filter well that collected and treated the effluent from a septic tank receiving wastewater from a single household in Sweden. A volume of 800 dm^3 Polonite (560 kg) was packed into the filter well and the approximate volume of wastewater treated was 70 m^3. The average outlet P concentration was below 1 mg P dm^{-3} and the efficiency of P removal was above 90%. After approximately 24 months, the outlet P concentration started to rise steadily, showing that the material was no longer efficient. The material (Polonite-ww) was removed from the filter, air-dried and stored for a few weeks before being applied to the soil. As the wastewater organic matter (OM) tended to accumulate on the top of the Polonite-filled filter well during treatment, mixing the entire material ensured that OM content was homogeneously dispersed, and probably quite low. The removal of nitrogen (N) by Polonite during wastewater treatment and the total N accumulation in the material is generally low (Hylander et al., 2006; Renman, 2008). For this reason, neither OM nor N was investigated in this work.

2.2. Field experiment

The experimental field station is located in Czarny Potok, a southern region of Poland within the Carpathian Mountains (20°54′E, 49°24′N, altitude 720 m asl). The soil used as mountain meadow is classified as a Dystric Cambisol that consists of 60% sand, 38% silt and 2% clay (sandy loam) (FAO-ISRIC-ISSS, 1998), with a C/N ratio of 12.5 and pH_{H_2O} of 5.2. The water field capacity of the soil is 0.30–0.35 (v/v) (Zaleski and Kopeć, 1999). The mean annual precipitation in this mountain region over the 30 years preceding the experiment was 821 mm and the mean annual temperature was 5.8 °C, while the mean precipitation and temperature in the April–September period were 543 mm and 11.7 °C respectively (Kopeć, 2000).

A section of approximately 125 m^2 (10 m × 12.5 m) of unused field was divided into 20 plots of 4 m^2 each (2 m × 2 m) with 50 cm spacing. The natural meadow consisted of an established grass cover (*Gladiolo-Agrostietum*) and no weeding or herbicide application was performed. Each plot received fertilizer on 8 May 2007 (day 0) according to one of five different treatments:

1. N (nitrogen)
2. NPK (nitrogen, phosphorus and potassium)
3. NK + Polonite-ww (nitrogen, potassium and Polonite-ww)
4. Polonite-ww (Polonite-ww)
5. Lime (CaO)

Nitrogen (N) was added as NH_4NO_3 containing 34% N to reach a rate of 50 kg N ha^{-1} (0.04 kg NH_4NO_3 per plot). Potassium (K) was applied as KCl with 60% K_2O to reach 60 kg K ha^{-1} (0.02 kg KCl per plot). Phosphorus (P) was added as triple superphosphate (0.04 kg per plot) containing 46% P_2O_5 or as P bound to Polonite-ww (5.3 kg Polonite-ww per plot), in both cases to reach a rate of 20 kg P ha^{-1}. This ratio, $N_{50}P_{20}K_{60}$, has been used in previous studies carried out in this mountain meadow during the past 30 years (Kopeć, 2000). Lime containing 32% CaO was added to reach the same level of Ca as in Polonite-ww amendments (Table 1). Each treatment was performed in four replicates. Prior to use, Polonite-ww was crushed and sieved to a fraction <2 mm in order to have a homogeneous distribution and enhances the release of P and other elements to the soil solution. Fertilizer compounds, Polonite-ww and lime were directly applied and equally distributed on the soil surface by hand. This experimental design aimed at comparing different treatment alternatives for the management of the meadow and contrasting the effects of applying Polonite-ww (with and without NK fertilization) with known fertilization practices and conventional liming.

The meadow plants (mainly grass) were harvested on 6 July (day 59) and 14 September (day 70). The plants were cut manually from a sub-area of 1.45 m × 2 m at approximately 1 cm above the soil surface, dried at 55 °C, weighed, chopped and milled. Initial soil samples (day 0) and soil samples taken after the second harvest (day 70) were collected manually from the top horizon.

2.3. Sample analysis

Polonite samples before and after wastewater treatment, initial soil samples and soil samples after the second harvest from each plot were analyzed for total element concentrations by means of atomic spectrometry using an ICP-AES JY 238 Ultrace after digestion with nitric and perchloric acids by heating (90–165 °C) for 3–4 days and subsequent filtration (Strowska et al., 1991). The pH was measured in a 1:2.5 (w/v) material:water or soil:water suspensions (Klute, 1996). “Plant available” nutrient forms were measured as ammonium lactate (AL)-extractable P and K in acetic acid (Egner et al., 1960), and as $CaCl_2$-extractable Mg according to the Schachtschabel method (Litynski et al., 1976). Soil hydrolytic acidity (Hh) was determined according to the Kappen method using 1 mol dm^{-3} CH_3COONa solution (Klute, 1996). The Hh is also termed as exchangeable acidity, and in most soils it is composed of (i) exchangeable H^+, (ii) exchangeable Al present as either Al^{3+} or partially neutralized Al–OH compounds such as $AlOH^{2+}$ or $Al(OH)_2^+$ and (iii) weak organic acids (Carter and Gregorich, 2008). The base cation (Ca^{2+}, Mg^{2+}, K^+ and Na^+) concentrations were determined by atomic spectrometry using an AAS Solar M6 System after extraction with a 0.5 mol dm^{-3} NH_4Cl solution for 24 h (Kociałkowski et al., 1984). Total exchangeable base (TEB) cations concentration, cation exchange capacity (CEC) and base saturation (BS) percentage were then calculated as follows:

$$\mathrm{TEB} = [Ca^{2+}] + [Mg^{2+}] + [K^+] + [Na^+] \quad (1)$$

$$\mathrm{CEC} = \mathrm{Hh} + \mathrm{TEB} \quad (2)$$

Table 1
The properties and chemical composition of Polonite (before and after wastewater treatment) and initial soil.

Parameter	Polonite	Polonite-ww	Soil
Particle size (mm)	2–5.6	<2	n.d.
Bulk density (mg m^{-3})	0.7	n.d.	1.1
pH	~12.0	9.7	5.2
P (g kg^{-1})	0.4	1.5	0.6
K (g kg^{-1})	8.5	7.7	2.0
Ca (g kg^{-1})	189	176	1.1
Mg (g kg^{-1})	4.5	5.2	4.2
Al (g kg^{-1})	25.4	24.3	57.4
Fe (g kg^{-1})	19.5	19.5	11.0
Mn (mg kg^{-1})	125	134	313
Zn (mg kg^{-1})	21.3	38.6	61.6
Cu (mg kg^{-1})	<6	13.1	7.4
Cr (mg kg^{-1})	49.6	50.1	n.d.
Ni (mg kg^{-1})	19.1	18.3	n.d.
Cd (mg kg^{-1})	<2	n.d.	n.d.
Available P (mg kg^{-1})	n.d.	267	38.4
Available K (mg kg^{-1})	n.d.	279	235
Available Mg (mg kg^{-1})	n.d.	5.6	99.1
Hh (cmol(+) kg^{-1})	n.d.	n.d.	9.1
TEB (cmol(+) kg^{-1})	n.d.	n.d.	3.7
CEC (cmol(+) kg^{-1})	n.d.	n.d.	12.8
BS (%)	n.d.	n.d.	28.7

Polonite-ww = Polonite after 28 months of household wastewater treatment; n.d. = no data.