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Improvement of the solubility of rock phosphate by co-composting it with organic components

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One possible way to improve the solubility of phosphate rock is by co-composting it with organic substances. Four variants of composts were made in a biomass composting bioreactor. Ground phosphate rock (GPR) and shredded barley straw, pine sawdust as well as beet pulp pellets were used as compost components. The four composts were different from one another in the type and amount of organic components. The composts were granulated in a pelleting press. Changes in the solubility of phosphorus were assessed via chemical analyses and P-recovery efficiency calculated from the data achieved in a pot experiment. Solubility of ground phosphate rock was increased resulting from co-composting with organic substances, which meant that bioavailability of phosphorus increased. All the tested composts were characterized by a higher ratio of ammonium citrate soluble phosphorus to total phosphorus than non-composted GPR. Co-composting GPR with all the tested organic components yielded better effects than composting it with straw alone. The four composts were characterized by a slow release of P, which justifies our expectation that they will produce residual effects in the years following their application.

Keywords: compost, straw, sawdust, beet pulp, phosphorite, phosphorus availability to plants.

INTRODUCTION

Production of high concentration phosphate fertilizers takes place in expensive facilities, which generate an unfavourable influence on the environment. It is therefore essential to search for new methods of manufacturing phosphate fertilizers, which would be less costly and have a weaker impact on the environment than the conventional technologies[1, 2]. New methods could rely on the use of natural ground phosphate rock, not chemically processed, provided that its solubility is improved. Phosphate compounds found in unprocessed phosphate rock are not easily available to plants. The solubility of phosphate rock is increased, for example, by mixing it with sulphur[2–5]. Another way of increasing phosphate rock solubility, perhaps worth more attention, is by co-composting it with organic matter. Products of the metabolism of microorganisms which decompose organic matter break down phosphate, releasing plant available phosphate compounds. The improved solubility of phosphorus achieved by co-composting is a result of the effect on phosphate rock produced by organic acids, humic substances and other chelating substances secreted by microorganisms while decomposing organic matter[6–7]. This process continues in soil amended with such composts[8–9]. Organic materials used for co-composting could be, for instance, rice straw[9–11], wheat straw[6], manure[12], beet pulp[13], or other plant residues[14–15]. The co-composting process is usually enhanced by inoculation with phosphate-solubilizing bacteria[9, 11] or farmyard manure, which is a good source of these microorganisms[10].

The recommended ratio of organic fraction to phosphate rock in such composts is 4:1[9, 16]. The C:N ratio is just as important and should be kept within the range of 35:1–25:1[11, 14]. The world literature emphasizes the importance of the search for less expensive sources of phosphorus for agriculture[13, 17].

MATERIALS AND METHODS

Bioreactor for biomass composting

Composts were made in a bioreactor manufactured by *Automatyka i Elektronika Przemysłowa*, a Polish company based in Łódź (Fig. 1). This bioreactor has been designed for composting organic substances under controlled thermal conditions. The main elements of the bioreactor are a mixing device and an air preparation module. The mixing device is a rotary aerated cylindrical chamber of the working capacity of 0.2 m^3, fitted with a compost temperature sensor. The air preparation module is used to warm up air to a set temperature. The composting process is controlled by feeding vapour-saturated air of the requested temperature into the mixing chamber. During the composting process, the compost temperature is read and recorded.

Preparation of composts

The tested composts were made from shredded barley straw, pine sawdust and dry beet pulp pellets. Straw was obtained from fields at the Experimental Station in Jelcz-Laskowice, Institute of Soil Science and Plant Cultivation (IUNG); sawdust came from a small carpenter's workshop and beet pulp pellets originated from a sugar plant in Swidnica-Pszenno. The composts were enriched with ground phosphate rock (GPR), nitrogen in the form of urea (46% N) and granulated cow manure. Before co-composting, straw was cut in a straw shredder into the 6–8 cm long pieces. The ground phosphate rock from Morocco contained 13.38% total P, 6.42% formic acid-soluble P, 3.55% citric acid-soluble P, 1.48% ammonium citrate-soluble P, 0.048% H_2O-soluble P; 40.2% total Ca, 0.39% Fe, 0.30% Mg and 415, 29, 28, 26, 22, 17, 6 and 8 mg · kg^{-1} Zn, Cd, Ni, Cr, Cu, Mn, Pb and As, respectively. Particle size distribution for GPR was: 55% pass through a sieve with a mesh

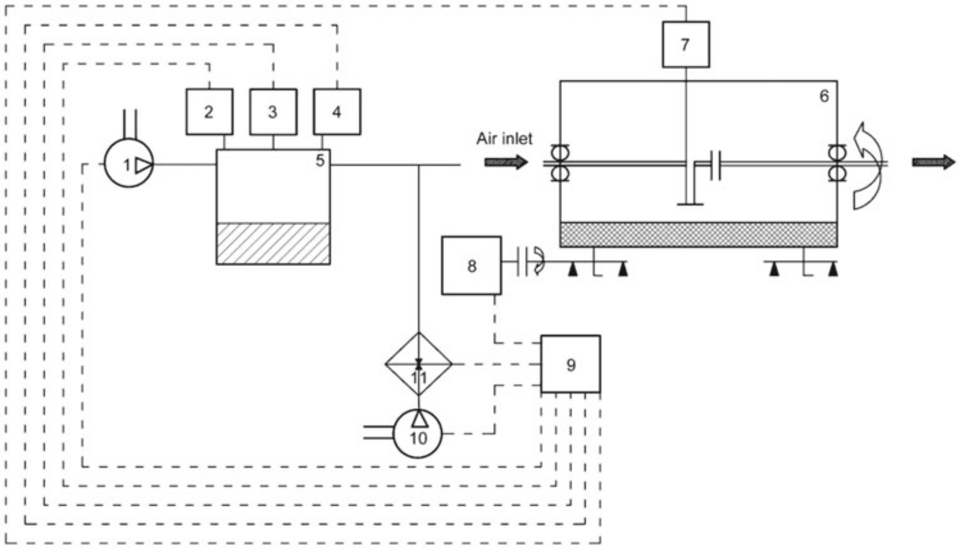

Figure 1. Schematic diagram of the bioreactor: 1 – air blower, 2 – water temperature sensor, 3 – air temperature sensor, 4 – water level gauge, 5 – water tank – humid air preparation, 6 – rotating composting chamber, 7 – compost temperature sensor, 8 – driving section, 9 – PLC control system, 10 – air blower, 11 – air heating unit

of 0.063 mm, 80% – 0.125 mm and 87% – 0.160 mm. Granulated cow manure contained 3.2% N, 0.7% P, 1.3% K, 1.7% Ca and 3.6% Mg. The characteristics of the organic components are given in Table 1.

Table 1. Characteristics of organic components used for making composts

Component	C org. %	N %	P %
Barley straw	43	0.6	0.25
Pine sawdust	45	0.1	0.01
Sugar beet pulp pellets	34	1.0	0.10

Four variants of composts were prepared (A, B, C and D) at the at the IUNG Experimental Station in Jelcz-Laskowice. They were made by mixing different quantities of organic components, ground phosphate rock (GPR) and urea fertilizer in a bioreactor (Table 2). The mixtures were enriched with dry manure in order to improve their microbiological activity. The composition of composts was determined taking into account the studies of other authors, who achieved positive results[6, 9, 11, 14].

The total dry matter of each batch was about 45 kg; the ratio of organic components to the GPR was 4:1 and the carbon to nitrogen ratio was 30.3–31.4. Water was added to each batch placed in the bioreactor until the moisture content reached 60%. The moisture of composted mixtures was checked with a moisture analyzer.

The air flow intensity was 3.2 $m^3 \cdot h^{-1}$ and the air temperature was 50°C. After three weeks, the mixtures were transferred from the bioreactor to round plastic containers of the capacity of 90 l (60 x 50 cm), in which they matured for 1–2 months. The containers were covered with plastic film to avoid excessive moisture content changes.

The composts were granulated in a pelleting press at the INCO-VERITAS Production Plant in Susz. A series of pelleting trials was performed to test the effect of compost moisture on the pelleting process and quality of pellets. Before the pelleting, composts were additionally dried to lower the moisture content to less than 49%. The pelleted composts were subsequently dried on sieves in a drying chamber until the moisture content fell below 8%.

Pot experiment

The effect of co-composting on the GPR solubility and, consequently, on the availability of phosphorus to plants, has been analyzed in a pot experiment conducted at the IUNG Experimental Station in Jelcz-Laskowice. The fertilizing effect of 4 variant composts as a source of phosphorus was examined in comparison to GPR and triple suprphosphate (TSP) and against a control treatment without phosphorus (0). The experiment was performed with 4 replications in a completely randomized design.

Wagner pots of the capacity of 9 kg were filled with light soil (loamy sand), slightly acidic (pH 5.5) and very poor in plant-available phosphorus (24 mg $\cdot$ kg^{-1} Egner--Rhiem P).

The tested plants were pea as the main crop and cabbage as the catch crop harvested 2.5 months after sowing. Pea had been selected for the experiment because legumes are better at utilizing phosphorus from PR than

Table 2. Composition of composts (kg)

Component	Compost A	Compost B	Compost C	Compost D
Phosphate rock (PR)	9	9	9	9
Beet pulp pellets	–	18	12	6
Barley straw	36	–	12	15
Pine sawdust	–	18	12	15
Granular urea (46% N)	0.63	0.57	0.57	0.70
Granulated cow manure	0.05	0.05	0.05	0.05
Organic components/PR	4:1	4:1	4:1	4:1
C/N	30.3	30.9	31.4	31.3

other plants[13, 16]. Pre-sowing application of phosphorus in the form of the composts had been carried out only before the pea was seeded. The same dose of phosphorus, 1 g P per pot, was introduced to all the pots except the control. Doses of composts were calculated based on their total P content (table 4). Cabbage did not receive phosphorus fertilization because slow release of phosphorus from the composts was expected. For both pea and cabbage, pre-sowing basic fertilization was given: 1 g N (ammonium nitrate), 2 g K (potassium chloride) and 0.5 g Mg (magnesium sulfate) per pot as chemical reagents (99.9%, Chempur, Poland). Additionally, both crops were fed with 1 g of nitrogen per pot by single irrigation of ammonium nitrate solution: pea – 2 moths, and cabbage – 1 month after sowing. During the whole growing season, the plants were watered with deionized water. Soil moisture was maintained on a constant level of 60% water field capacity. Seed and straw yields of pea were determined as well as the yield of the whole aerial part of cabbage plants cut 5 cm above the ground. Treatment averaged samples of pea seeds and straw as well as whole aerial parts of cabbage were taken for chemical analyses.

Chemical analyses

All chemical analyses of the tested fertilizers were performed in the laboratory of Wroclaw University of Technology in the laboratory certified by ILAC-MRA and Polish Centre of Accreditation (certificate no. AB 696). Concentrations of particular forms of phosphorus in phosphate rock and in the composts were analyzed according to the Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilizers[18]. Total phosphorus soluble in mineral acids as well as phosphorus soluble in 2% formic acid, in 2% citric acid, in 2% neutral ammonium citrate and phosphorus soluble in water were determined. Determination of extracted phosphorus compounds was achieved by precipitation of phosphorus as quinoline phosphomolybdate in acid medium. Analysis of macronutrients and heavy metals in phosphate rock was made by ICP optical spectrophotometry after mineralization of samples in *aqua regia* and in a microwave oven at 1200°C according to procedure no. LA3b-012 (As, Ni, Pb, Cd), LA3b-013 (Ca, Mg) and LA3b-014(Cr, Cu, Fe, Mn, Zn).

Chemical analyses of organic components for composting (barley straw, pine sawdust and sugar beet pulps), as well as plant and soil samples from the pot experiment, were made at a laboratory of the Institute of Soil Science and Plant Cultivation in Pulawy, certified by Polish Centre of Accreditation (certificate no. AB 339). Determinations of the content of phosphorus and nitrogen in organic components and plant material by flow spectrophotometry (CFA) were preceded by wet mineralization of the samples (concentrated sulphuric acid + hydrogen peroxide) according to procedure no. PB 48.1 Edition I:2002. The total organic carbon (TOC) in organic components for composting was determined using the IL 550 TOC analyzer, according to the PN-ISO 10694:2002, and PN-EN13137:2004 regulations.

Available phosphorus in soil samples was determined by Enger and Riehm's method with calcium lactate (DL)[19] and soil pH was measured by potentiometry in KCl solution[20].

Statistical calculations

The calculated P-recovery efficiency values were submitted to analysis of variance for one-factorial experiment. Tukey's test ($\alpha<0.05$) was used in assessment of differences between treatments. All statistical computations were aided by the computer software programme Statistica 6.0 PL.

RESULTS AND DISCUSSION

The composts were characterized by an average moisture content of 63–76% and needed to be additionally dried up before pelleting. The tests have demonstrated that compost pelleting is feasible when the moisture content in a given compost does not exceed 49%. When such dried-up composts were pelleted, no subpellets were generated.

Pelleted composts were characterized by low bulk density, much different from that found in classical fertilizers (Table 3). Compost D had the lowest density and the highest size diversity of pellets.

The content of particular forms of phosphorus in the pelleted composts is presented in Table 4. The highest total content of P (TotP) occurred in compost B (4.70%), while the lowest one (3.10%) was found in compost D. At the same time, compost D had the highest content of formic acid (FAcP) and citric acid soluble phosphorus (CAcC), but the lowest percentage of phosphorus soluble in ammonium citrate (CAmP) and in water (H2OP).

Table 3. Characteristics of compost pellets

Mesh size [mm]	Plus mesh fraction [%]			
	Compost A	Compost B	Compost C	Compost D
6.3	31.09	80.36	89.22	49.44
5.0	68.44	16.85	9.81	13.38
2.5	0.41	1.43	0.56	17.04
1.6	0.04	0.68	0.15	8.24
1.0	0.01	0.29	0.06	5.72
0.8	0.01	0.05	0.02	2.08
Minus mesh fraction (%)	0	0.34	0.19	4.10
Bulk density ($g \cdot dm^3$)	567	298	346	223

Table 4. Content of different phosphorus forms in the studied composts in %

P form	Compost			
	A	B	C	D
Total P in mineral acids (TotP)	4.07	4.70	4.20	3.10
P soluble in 2% formic acid (FAcP)	1.30	1.34	1.20	1.57
P soluble in 2% citric acid (CAcP)	1.51	1.63	1.42	2.10
P soluble in neutral ammonium citrate (CAmP)	0.65	0.63	0.79	0.61
P soluble in H_2O (H2OP)	0.016	0.017	0.015	0.013

Similar quantities of total phosphorus in phosphate organic composts, i.e. around 3.6–3.9%, were obtained by Nishanth and Biswas[11].

The degree of PR decomposition is manifested by the ratios of particular forms of phosphorus to total phosphorus, and the most important ones for the assessment of phosphorus availability to plants are the CAmPT/TotP and H2OP/TotP proportions. Ratios of particular forms of phosphorus in the analyzed pelleted composts were compared to analogous proportions in ground phosphate rock (GPR) which did not undergo composting. Compost D had a higher FAcP/TotP ratio than GPR while composts A and D had a superior CAcP/TotP ratio to that in GPR. Compared with GPR, all the analyzed composts had a higher CAmP/TotP ratio and the H2OP/TotP ratio was higher in composts A and D (Fig. 2). The results imply better plant availability of phosphorus from all the analyzed composts than from GPR, with compost D demonstrating the best parameters.

An increase in the solubility of PR leads to an improved availability of phosphorus to plants. The assessment of the availability of phosphorus forms found in the tested fertilizers was performed by comparison of P-recovery efficiency values (PRE). For this aim, yields of the crops grown in the pot experiment were determined, including their concentration of phosphorus, and then the uptake of phosphorus with yield was estimated. Based on the uptake, the PRE was calculated from the formula:

$$PRE\ (\%) = (U_{FT} - U_0)/P_{FT} \times 100$$

where: U_{FT} – P uptake at fertilized treatment in mg per pot, U_0 – P uptake at the control treatment in mg per pot, P_{FT} – amount of P applied at fertilized treatment in g per pot;

P uptake in mg per pot = (yield in g per pot x P concentration in %) x 10.

The P-recovery efficiency values in the analyzed composts and for GPR computed for pea did not exceed 1% and the differences between treatments were non-significant (Fig. 3). The PRE for superphosphate was much higher (7.1%). Significant differences in PRE between the composts and GPR appeared for cabbage grown as the catch crop. There, the PRE for all the composts except compost A was significantly higher than for GPR. At the same time, it was on the same level as the PRE for superphosphate. This confirms that phosphorus was much more available to cabbage when derived from the composts rather than from GPR, to a point where the

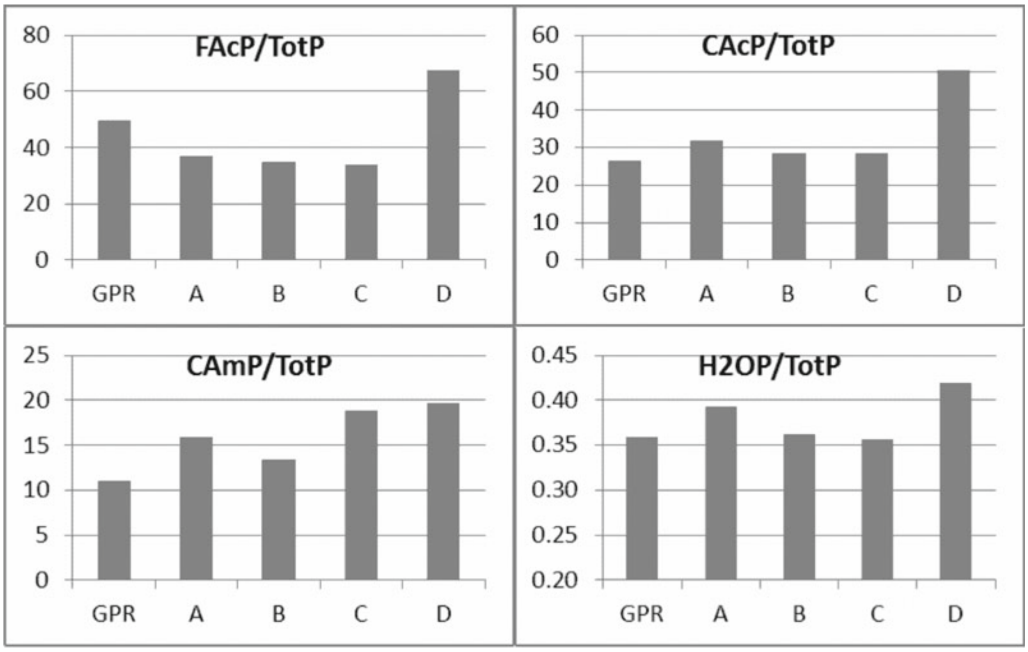

Figure 2. Ratios of different forms of phosphorus (CAmP-ammonium citrate, CAcP-citric acid, FAcP-formic acid soluble P) to content of total phosphorus (TotP) in composts (A, B, C, D) versus ground phosphate rock (GPR)

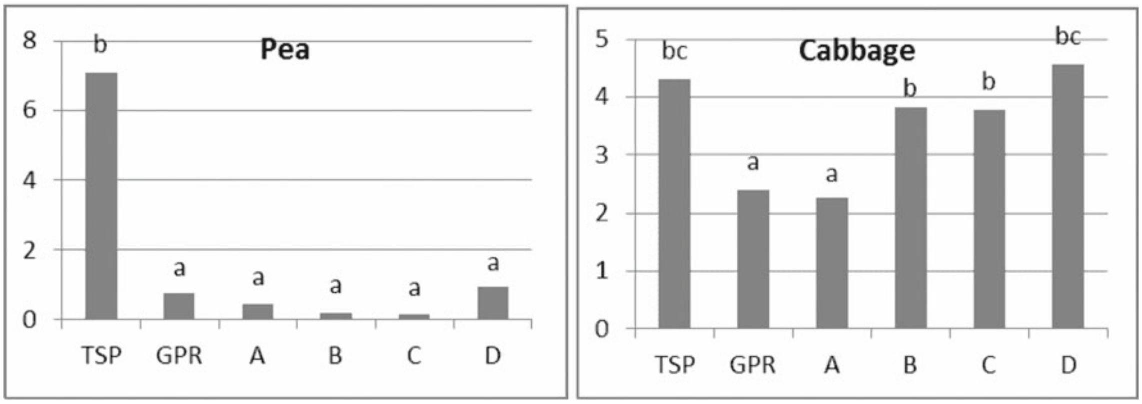

Figure 3. P-recovery efficiency for pea and cabbage in %. TSP-triple super phosphate, GPR- ground phosphate rock, A, B, C, D – tested composts. Bars marked with the same letters are not significantly different according to Tukey's test at $\alpha < 0.05$.

P availability was similar to superphosphate. Although some other authors[9] achieved satisfactory results when composting phosphate with straw alone, compost A did much worse than the other composted mixtures tested in our study. A mixture of beet pulp pellets, pine sawdust and barley straw in composts B-D yielded much better results than compost A. Apparently, that ratio of beet pulp pellets to sawdust and straw was an important factor. Compost D proved to be the best source of phosphorus for cabbage, where beet pulp pellets ratio to other two components was 1:5 (Fig. 3, Table 2).

Improved bioavailability of phosphorus from composts to the catch crop proves that phosphorus undergoes slow release from these fertilizers. It is therefore predictable that they will produce a residual effect in the second year after their application.

CONCLUSIONS

Composts pelleted in a pelleting press need to have a moisture content below 49%.

Co-composting GPR with such organic components as barley straw, pine sawdust and beet pulp improved its solubility, which increased the bioavailability of phosphorus.

Co-composting raised the proportion of formic acid and citric acid soluble phosphorus to total phosphorus only in compost D.

All the analyzed composts were characterized by a higher ratio of ammonium citrate to total phosphorus than found in non-composted ground phosphate rock.

Three of the tested composts (B, C and D) had a significantly higher P-recovery efficiency for the catch crop than GPR.

Co-composting GPR with all the three tested components produced better effects than co-composting it with straw alone.

Pelleted phosphate organic composts were characterized by slow release of P, which justifies the expectation that they will produce residual effects in the years following fertilization treatment.

It is necessary to check the residual effect of the composts in a two-year agricultural experiment.

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