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Efficiency of Natural Phosphate (Apatite) Dissolution by Vegetal Organic Matter

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Abstract

Natural phosphates (Apatite) are the main sources of phosphorus, one of the three major chemical elements for plant development. The present work aims to study the efficiency of dissolution of natural phosphate from Togo during composting of a mixture of this ore with different types of vegetal matter. Phospho-composts of mixtures of ore and cow dung (A+P), poultry droppings (B+P), nymphea (C+P), domestic organic waste (D+P) and vegetal organic composts without phosphate (A, B, C and D) were elaborated. Determination of available phosphorus concentrations by the colorimetry method (HACH DR 3800) in composts and phospho-composts was realized. Analysis results revealed that organic matter has a solubilizing effect on natural phosphate. Nymphea phospho-compost has the best ore dissolved because its assimilable phosphorus content is the highest (0.88%). These results also showed that phospho-composts maturation time has a beneficial effect on the ore dissolution.

Keywords

Natural Phosphate, Apatite, Available Phosphorus, Organic Matter, Compost, Dissolution

1. Introduction

Yields increasing in agriculture has led to excessive use of chemical fertilizers, with negative environmental consequences clearly established in previous studies [1]. It urges the development of innovative approaches to create new types of ecological fertilizers, highlighting the role of biodegradable vegetal organic matter. Natural phosphates (apatite), like the one exploited in Togo, are main sources of phosphorus, one of three key elements for plant growth. This mineral has a P_2O_5 content of approximately 28.20% [2]. However, the low solubility of these minerals is a challenge for their direct use as fertilizers [3]. Phospho-composting then appears as a practical approach to valorize them in agriculture [4]. This work aims to study the dissolution efficiency of natural phosphate from Togo during composting of organic matter and ore mixtures.

2. Materials and Methods

Biodegradable materials come from plant or animal sources, namely cow dung, poultry droppings, nymphea (nenuphar), and household waste. The choice of these types of biodegradable organic matter is due to their common use for agricultural soil amendment [5] [6]. The mineral material is natural phosphate from Togo, which is an apatite (**Figure 1**).

(a) Nymphea (b) Cow dung (c) Poultry dropping (d) Household waste (e) Natural phosphate

Figure 1. Biodegradable materials and natural phosphate (a; b; c and d).

Phospho-composts were developed for six (06) months by constituting ore-organic matter mixtures: phosphate and cow dung (A+P), phosphate and poultry droppings (B+P), phosphate and Nymphéa (water lily) (C+P), and phosphate and domestic biodegradable waste (D+P) in a ratio of 50 kg of ore and 450 kg of organic matter. 100% organic composts were also developed under the same conditions.

Organic matter content in our composts was calculated after calcining 10 g of each sample at 550˚C using the formula below:

$$\%\mathbf{OM} = \frac{\mathbf{m_1} - \mathbf{m_2}}{\mathbf{m_1}} \times \mathbf{100}$$

%OM: organic matter content;

m_1: mass of dry matter before calcination;

m_2: ash mass after calcination.

Total organic carbon content (TOC) in the different samples was calculated using the following formula:

$$\%\ \mathbf{TOC} = \frac{\mathbf{OM}(\%)}{\mathbf{1.724}}$$

For the determination of nitrogen content, 0.5 g of compost was mixed with 10 ml of concentrated sulfuric acid and 0.5 g of Kjeldahl catalyst. Digestion was carried out hot until samples turned white. After cooling, the solution was diluted with 100 ml of distilled water and then subjected to distillation. A control sample was also prepared under the same conditions. During distillation using a nitrogen distiller, the diluted solution was combined with 50 ml of 40% sodium hydroxide in a dedicated flask, and 10 ml of 1N boric acid was poured into a 250 ml Erlenmeyer flask. Distillate was titrated with 0.02 N sulfuric acid (H_2SO_4) in the presence of a colored indicator The total nitrogen content was determined using the following formula:

$$\%N = \frac{1.4 \times N \times (Ve - Vt)}{P}$$

%N: Total Nitrogen Content.

Ve: sample volume (ml).

Vt: control sample volume (ml).

N: normality of the titrant solution (0.02 N sulfuric acid).

P: weight of test sample (g).

The Olsen method has been used to extract available phosphorus from compost. 2.5 g of compost is placed in a container and 50 mL of 0.5 M sodium bicarbonate solution at pH 8.5 is added. The mixture is subjected to continuous stirring for 30 minutes to promote solubilization of available phosphorus. The solution is filtered to separate the liquid phase containing the available phosphorus from the solid residues [7].

Determination of total phosphorus and available phosphorus content in samples was carried out using a HACH DR 3800 molecular absorption spectrometer, in accordance with the guidelines of the DR 3800 procedure manual. Measurement parameters of total phosphorus and available phosphorus are reported in Table 1.

Table 1. Phosphorus measurement parameters.

Element	Technic	Matterail	References Norms
Available Phosphorus	Colorimetry	HACH DR 3800	Method 8114 of procedure DR3800
Total Phosphorus	Colorimetry	HACH DR 3800	Method 10127 of procedure DR3800

Extraction, characterization, and titration of humic substances are carried out after oxidation of the sample by potassium permanganate ($KMnO_4$) under alkaline conditions. Forty-five milliliters of ultrapure water were added to five (05) grams of compost, followed by slow stirring for two hours at room temperature. This operation promoted desorption of water-soluble compounds. The solid obtained, containing organic matter, was then centrifuged at 4000 rpm for 15 minutes at 4˚C. In a second step, a 0.1 N alkaline NaOH solution was introduced into the tube containing the solid. The mixture was subjected to the same conditions of stirring, allowing solubilization of the organic matter. Five milliliters of the filtrate were taken into a 50 mL beaker. To this sample, 10 mL of 0.1 N NaOH solution and 20 mL of 0.1 N potassium permanganate ($KMnO_4$) were added. The mixture was brought to a boil for 10 minutes to oxidize the organic compounds present.

After the solution had cooled completely, 20 mL of oxalic acid and 10 mL of concentrated sulfuric acid (6 N) were added to neutralize the excess permanganate and stabilize the solution before titration by gradual addition of 0.1 N $KMnO_4$.

For FTIR analysis, 2 mg of compost, previously dried at 105˚C for 24 hours, was collected. The sample was finely ground and then placed directly on the ATR of the spectrophotometer. Uniform pressure was applied using the integrated pressure arm. This configuration allowed us to record our infrared spectra between 350 and 4000 cm^{-1} using the spectrophotometer FT-IR JASCO FT/IR-4700.

3. Results and Discussions

3.1. Composts Characterization

Compound must meet a number of criteria before it can have a compost label, in particular its carbon (C) and nitrogen (N) content, organic matter (OM) rate, and C/N ratio [8]. Characterization of our samples essentially consisted of determining their organic matter rate, their carbon and nitrogen concentrations, and C/N ratio (**Table 2**).

Data in this table show that only compost (D+P) obtained from a mixture of phosphate ore and household waste has a C/N ratio below the accepted standard (C/N >8). Other composts or phospho-composts have a ratio either higher than 8 or slightly lower (case of A+P, D and D+P composts).

All samples analyzed have organic matter (OMT) contents between 10 and 30%. Their total organic carbon contents (TOC) are between 10 and 17%, except for composts from household waste (D and D+P). Their total nitrogen (NTK) contents comply with accepted compost standards (%N < 3) [8]. Analysis results allow us to conclude that our materials meet compost criteria, except for the two composts from household waste.

Table 2. Organic matter, carbon (C), and nitrogen (N) contents in six (06)-month mature composts.

Compost	OMT (%)	TOC (%)	N-NTK (%)	C/N
A	17.39 ± 0.35	10.09 ± 0.2	1.17 ± 0.04	8.68 ± 0.51
A+P	19.08 ± 0.09	11.06 ± 0.05	1.45 ± 0.36	7.62± 1.79
B	19.60 ± 0.73	11.37 ± 0.42	1.31 ± 0.18	8.06 ± 1.3
B+P	21.57 ± 2.95	12.51 ± 1.71	1.22 ± 0.23	10.37 ± 3.17
C	22.07 ± 0.12	12.80 ± 0.07	1.13 ± 0.02	11.03 ± 0.54
C+P	22.59 ± 2.33	13.10 ± 1.35	1.16 ± 0.06	11.23 ± 0.26
D	21.6 ± 0.57	8.84 ± 0.43	1.31 ± 0.0	7.45 ± 0.83
D+P	21.27 ± 0.54	9.94 ± 0.6	1.5 ± 0.05	6.67 ± 0.6
Norme NFU 44051/Norme FAO	10 - 30*	10 - 17*	<3**	>8**

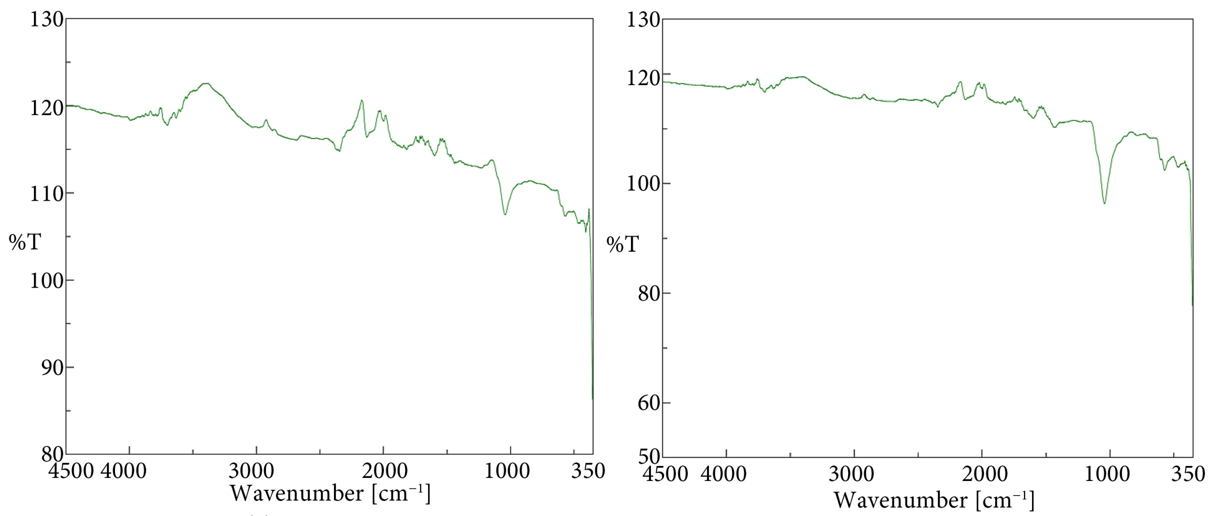
(**): Value of FAO standard [8], (*): Value of NFU 44-051 standard [9].

Materials maturity was assessed through the humification degree of composts and phospho-composts produced (Table 3). These humic substances result from organic matter decomposition, and the humification process was observed during the composting of waste [9]. Organic composts have higher concentrations of humic substances compared to phospho-composts. This difference is explained by the inhibitory action of natural phosphate, which would slow down the humification process [10].

Table 3. Humic Substance contents in six (06) month mature composts and phospho-composts.

Compost	HS (g/kg)	HSR (%)
A	47.08	42.53
A+P	34.74	34.54
B	63	55.35
B+P	48.48	40.39
C	55.64	43.45
C+P	46.86	35.82
D	54.6	61.71
D+P	45.54	45.71

- HS = Humic Substances.
- HSR = Humc Substance Ratio.



(a) Compost C

(b) Phosphor-compost C+P

Figure 2. Compost C and phosphor-compost C+P FTIR spectra (a and b).

FTIR spectra (Figure 2) obtained between 4500 and 350 cm^{-1} present several characteristic bands which allow us to identify the main organic functional groups in the sample. Bands between 2920 and 2850 cm^{-1} correspond to aliphatic C–H stretching vibrations, linked to the $-CH_2$ and $-CH_3$ groups. The low intensity of these bands indicates the presence of lignocellulosic, lipidic compounds, which tend to decrease with the progress of humification [11]. Absorption observed around 1650 cm^{-1} is attributed to C=O vibrations of carbonyls (acids, esters, amides). This region is known as an indicator of humic substances formation [12]. In the 1450 - 1375 cm^{-1} region, bands associated with deformations of the CH_2/CH_3 groups as well as vibrations of carboxylate ions (COO^-) are observed and linked to the progressive formation of humic salts. These FTIR analysis results confirm the presence of humic substances in our samples and the maturation of our composts and phospho-composts.

These different analysis results allow us to conclude that the compounds analyzed are compost materials.

3.2. Efficiency of Natural Phosphate Dissolution

Dissolution of natural phosphate by organic matter was assessed by available phosphorus (Pass) titration in our phospho-compost samples. Results of titration reported in Table 4 and Figure 3 show that available phosphorus concentrations in phospho-composts are higher than those in composts obtained with organic matter only. These results are in agreement with several previous works that have already highlighted the dissolution of phosphate ore during the composting of a mixture of ore and organic matter due to the action of humic substances.

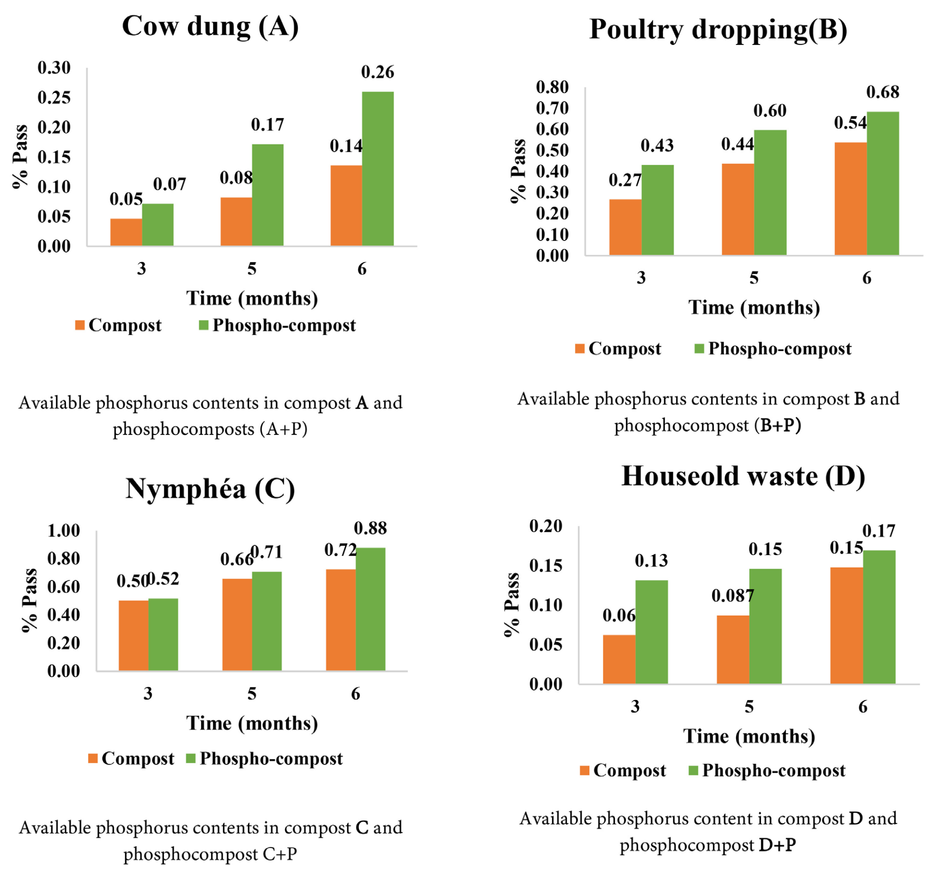


Figure 3. Available phosphorus contents in organic composts and phospho-composts (a; b; c and d).

Table 4. Available phosphorus (Pass) and total phosphorus (Ptot) contents in six (06) month mature composts and phospho-composts.

Echantillons	Pass (%)	Pt (%)
A	0,14	4,44
A+P	0,26	26,79
B	0,54	8,98
B+P	0,68	19,17
C	0,72	2,92
C+P	0,88	42,68
D	0,15	1,68
D+P	0,20	38,06

Nymphea presents better efficiency in apatite dissolution with an available phosphorus rate of 0.88% in C+P phospho.compost after six (06) months of maturation (Figure 4).

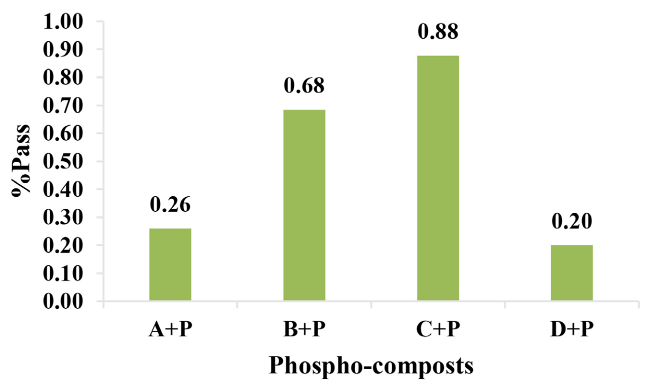


Figure 4. Available phosphorus contents in six (06) matured phospho-composts.

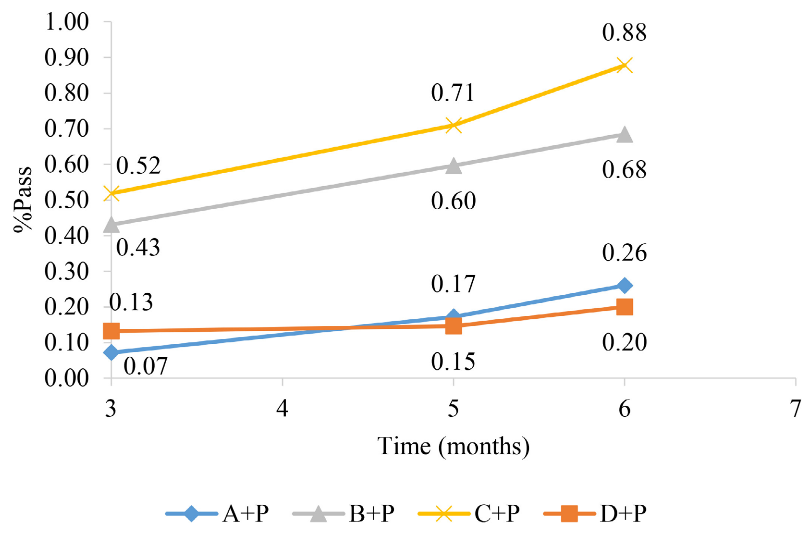
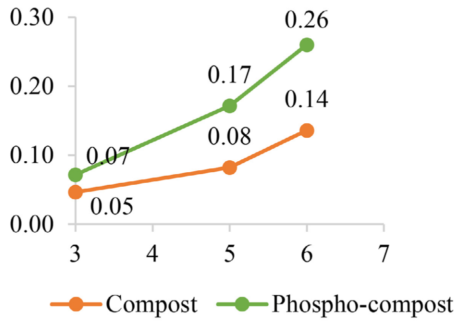


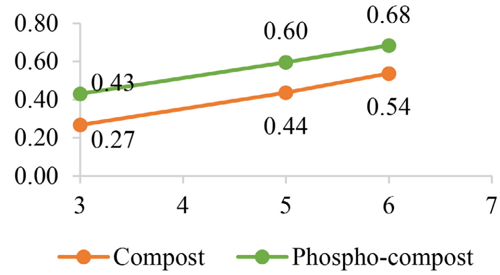
Figure 5. Available phosphorus contents in phospho-composts vs. maturation time.

Whatever the phospho-compost maturation time, Nymphea also has the best ore dissolution (C+P phospho-compost). In this work, fresh and homogeneous Nymphea plants are used, which explains this strong reactivity between organic matter and natural phosphate. We can conclude that the nature of organic matter is an important factor in the efficiency of natural phosphate dissolution. This conclusion is confirmed by the low rate of ore dissolution in household waste phospho-compost (D+P), which is a cocktail of organic materials sometimes containing inert materials (Figure 5).

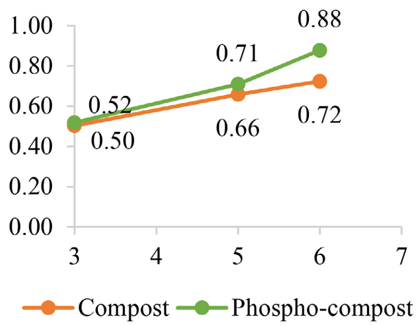
The effect of phospho-compost maturation time on phosphate dissolution has been evaluated. Three (03) months are required to mark the end of microbiological activity and the stabilization of the compost. The determination of available phosphorus content in samples started after 90 days from the process launch. The last measurement of this element was taken after 180 days. The different curves of Figure 6 show that available phosphorus contents increase with maturation time, indicating that time is a second factor which improves dissolution of natural phosphate (apatite) by organic matter.



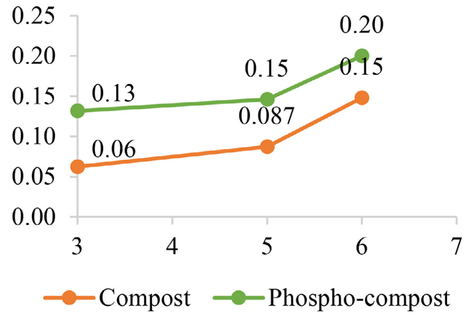
Maturation time impact on available phosphorus content in cow dung (A) compost and phospho-compost (A+P)



Maturation time impact on available phosphorus content in poultry droppings (B) compost and phospho-compost (B+P)



Maturation time impact on available phosphorus content in Nymphaea (C) compost and phospho-compost (C+P)



Maturation time impact on available phosphorus content in household waste (D) compost and phospho-compost (D+P)

Figure 6. Maturation time impact on available phosphorus content in organic matter composts and phospho-composts (a; b; c and d).

4. Conclusion

We have highlighted the dissolution of natural phosphate by organic matter during composting of ore and organic matter mixtures. Samples obtained from the analysis showed that the available phosphorus concentration in phospho-compost is higher than that in organic matter compost due to natural phosphate dissolution. This dissolution during the composting process depends on the nature of the organic matter and the time of maturation. Nymphea phospho-compost has a high concentration of available phosphorus (88%) after six (06) months of maturation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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