COMPOSTING OF AN IGNEOUS ROCK PHOSPHATE

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INTRODUCTION

In the soil literature it is generally accepted that igneous phosphate rocks (PR), metamorphosed igneous PR, metamorphosed sedimentary PR, and sedimentary PR with low degree of anionic substitution of PO_4 by CO_3, are all of very limited fertilizer value when applied directly to most soils (4, 6, 10, 14, 15, 22, 31, 32, 45). The crystallinity, physical size, and chemical nature of the calcium phosphate and its substitution products, all influence their reactivity, and thus solubility in soil and availability to plants (4, 6, 10, 15, 32, 17, 44). The availability of the P in PR to plants is also influenced by plant and soil properties. Plants with higher capacities to generate H ions (12), and absorb or adsorb PO_4 and Ca ions are better able to utilize P from PR (15). Similarly, soils with 'hunger' for Ca and P, due to acidity (low pH), low base saturation and ability to fix or immobilize P in clay, sesquioxides and microbial biomass, are better able to dissolve PR than those neutral or alkaline in pH with sufficiency or excess of Ca, or low biological activity (17, 45). The presence of some soluble Al helps dissolve the PR by complexation of F from the fluorapatite (4). Significant amounts of exchangeable or soluble Ca or Fe if present in a soil, refix the dissolved P into less soluble forms (11, 40, 37, 43). In the case of Fe, aerobic conditions and aging help decrease the plant-availability of Fe phosphates. It is being recognized now that although the chemical P-fixation capacity of soils, such as by active Fe, increases PR dissolution, the same also decreases plant-availability of the P from PR, and thus curtails the effectiveness of even sedimentary PR as a direct source of fertilizer-P (8, 21, 45).

Commercial fertilizer-P is produced from both igneous and sedimentary PR by acidulation, mostly by sulphuric acid. As sulphuric acid can also be produced by oxidation of S by soil bacteria, about 60 years ago workers at Rutgers University in U.S.A. solubilized PR by 'composting' soil, sulphur and PR (20). Even better results were sometimes obtained when some manure was mixed into the 'sulphur composts'. This was in accord with even earlier qualified successes with mixing of bonemeal or PR with manures and acidic peats in storage piles, or applying the PR to soils along with manures. Subsequent soil research led to virtual rejection of the sometimes expensive S and manure applications to soils as means of dissolving the soil-applied PR mainly due to considerations based on economics and reliable effectiveness (1, 15, 28). Even if the about 2.5 times of sulphuric acid needed for 1 unit PR is produced by oxidation of the S in a soil, it is more likely that the H_2SO_4 produced would interact with more reactive and prevalent compounds in soils, such as $CaCO_3$, or some Fe and Al compounds, rather than with the small amounts of less reactive PR.

Similarly, the acid products of decomposition of manures in soils may not help dissolve the PR significantly in soil. At the same time, greater the decomposition of the manure within a soil, more likely it is to reduce the supply of available-N to crop plants.

The importance of the plant-nutrient contents or quality of manures, and of their maturation by proper decomposition, to soil fertility, were recognized more fully during evolution of the scientific principles of composting by Sir Albert Howard and others in India, about 50 years ago (16, 35).

Compost is distinct from a pile of rotting refuse in that it is a designed environment where the plant nutrients are conserved while the carbonaceous bulk is decomposed to a relatively biostable humus-rich residue in a manner that destroys weed seeds, phytoinhibitory substances, and pathogens, without creating malodors that emanate from or remain in the product. These objectives are met by mixing various materials into a formulation where the C:N ratio, water:air ratio, macro- and micropores, are adequate for the desired decomposition (16, 35, 38).

It was established that aliphatic organic acids (e.g. citric, lactic, succinic), phenols, phenyl carboxylic acids, amino acids; and complex humic and fulvic acids, and mineral acid ions (NO_3, SO_4, and CO_3) are produced during the decomposition of organic matter in composts. In cold or anaerobic composts, the mineral acids are produced in lower amounts but the organic acids persist longer than in hot composts. Also, more heat is generated in aerobic (hot) composts than in the anaerobic composts. In both composts, phosphorus is usually a limiting factor for optimally rapid decomposition. At the same time, any sparingly soluble or insoluble calcium posphates added into the composts would be in intimate content with warm or hot solutions of organic and mineral acids that can solubilize the P source (16). As the chelating organic acids remove the Ca from the active phase the relased inorganic PO_4 ions are (a) utilized by microorganisms, to produce bioavailable compounds; or (b) loosely held by humic compounds with or without bridges of metal ions (7, 19). Even if some of the dissolved Ca and phosphate ions are reprecipitated, the products should be reactive amorphous compounds, such as α-tri-calcium phosphate (TCP), but not as crystalline unreactive compounds, such as β-TCP (Whitlockite) (33,34). Also it is likely that due to the presence of CO_2 such reprecipitation would occur in a CO_3:HCO_3 buffer so that some of the PO_4 ions would be substituted by CO_3 ions. It can be said that reactive sedimentary PR were originally laid down in CO_3: HCO_3 buffers of animal body fluids, oceans and inland seas. It has been shown that the reactivity of sedimentary PR increases with increasing substitution of PO_4 by CO_3 (4, 6). When more than 1 in 6 of the PO_4 ions are substituted by CO_3 the structure breaks down.

It should be emphasized that the overall pH of the compost does not have to be acidic to dissolve PR, as sufficient microenvironments exist in the compost around microbial colonies where the pH is acidic enough to help dissolve the PR.

Initial studies with phosphates in composts were to improve the quality of the product and hasten the process (2, 46, 16). It was also found that the P in the phospho-composts was more available to plants than even the comparable P from superphosphate, particularly in soils with high P fixing capacity (46). This effect of the compost can be attributed to: (a) the coating of P-fixing sites by organic compounds, (b) the continued production of carbonic and other acids by the slow decomposition of the composts in the soil (1, 2), and (c) the organic P in the phospho-composts may be taken by plants through hydrolysis by enzymes exuded by them into the soil around

their roots, without going through the general soil matrix (3, 13, 47).

Indeed much of the recent work on phospho-composts in India relates to the composting of a sedimentary PR to produce a material that is a suitable source of P for crops grown in calcareous soils of high P-fixing capacity (23, 24, 29, 30, 41, 42). The PR used most in studies reported recently from India is from Mussoorie. In this sedimentary PR, some of the Ca has been displaced by Na and Mg, and some of the PO_4 ions by CO_3. It is therefore a reactive PR, easy to dissolve, quite unlike an igneous PR. Under conditions where igneous PR are produced, or when magma heat a sedimentary PR, the CO_3 ions in carbonato-phosphates are expelled. The same occurs when bones are burnt so that the Whitlockite-containing bone ash is a much poorer source of fertilizer P than the bone meal containing mostly non crystalline hydroxy and carbonato-phosphates. Therefore, carbonato-phosphates were naturally not present in the igneous rock phosphate used in this study. The PR came from Cargill, Ontario, Canada (9, 39). The karst-type residium near the surface, under glacial till and lacustrine clay, shows signs of weathering up to the stage where much of the calcite, dolomite and FeS have been leached, and some Al released from degrading clay produced a layer of crandallite.

The beneficiated ore was found to be of little value as fertilizer when applied directly to a neutral sand, a calcareous clay or an acidic peat of low biological activity. In that sense the results were similar to those obtained by workers in Burundi (5, 18) who found that Matongo-Bandaga PR of igneous origin was only 1 to 5% as effective as superphosphate-P in 4 soils, an Oxisol, an Ultisol, a Vertisol and an Entisol. However, in a soil with high humus content - a Gleyic Oxisol or a Humic Oxisol - the corresponding value was 12% - thus suggesting that even an igneous PR is subject to the solubilizing effect of humus, and decomposing organic matter. Many workers have reported beneficial effects of certain manuring treatments on the direct use of PR in soils. As we felt that such effects of decomposing organic matter, and of the humus and CO_2 produced by it, can be intensified during composting, and in recognition of the need to utilize PR which is otherwise unsuitable for agronomic use, we tested the feasibility of composting an igneous rock phosphate from Cargill, Ontario, Canada.

MATERIALS AND METHODS

Some relevant properties of the materials used in this study are presented in table 1.

The 'hard' igneous phosphate rock (PR) from the Cargill deposit in northern Ontario, Canada, used in this study, is mostly macrocrystalline apatite with some crandallite, calcite and dolomite. The PR has 16% total P, 0.8% P soluble in citric acid, and 0.03% P soluble in ammonium citrate. About 44% of the beneficiated ore is >1 mm in size and 88% is >0.25 mm. Consequently, the crystallinity, chemical nature and pysical state all render the PR unsuitable for direct application to soils, particularly to those rich in active Ca or Fe.

Table 1. Materials used for composting

Materials	% Dry Matter	% Ash in D.M.	pH	Total % P	'Mobile' Humus * Index
Liquid Manure	8.2	18.8	7.3	0.65	166
Farm Yard Manure	26.7	22.2	8.2	0.16	129
Blood	12.9	4.8	3.9	0.13	14
Straw	86.4	7.3	8.0	0.11	39
Wood Waste	56.6	2.0	5.5	0.10	66
Peat	50.0	4.8	4.0	0.04	10
Phosphate Rock	100.0	98.0	7.0	17.11	

* O.D. at 450 mμ of a 1:100 extract in 0.25M $Na_2P_2O_7$

Aerobic (Hot) Composting

The compost heaps were generally 1 m high, trapezoidal in cross section, with base and top planes of 2 m x 1.0 m and 2 m x 0.3 m, respectively, according to a method developed in Canada (25, 26, 27, 36). The composting was done in July to October 1985 on a rough cement floor, under a roof, in an open shed, in Kapuskasing, northern Ontario, about 50 km from the Cargill deposit.

To build a compost heap, a basal 10 cm thick layer of peat or other fluffy material or mixtures used in the formulations (tables 2A and 2B) was laid loosely on the ground. Two 30 cm long ABS soil pipes of 10 cm diameter with two rows of perforation (1.2 cm diameter) were placed lengthwise on the basel layer, about 0.3 m from the margins. The two rows of perforations were both on the top side of the pipes. The rest of the material was then heaped on the pipes and shaped to fit the design. A light covering layer of peat, about 5 cm thick, was used in the end to curtail loss of ammonia, emanation of odours, the attraction for, and access of the waste to, flies.

In the composts where liquid manure was used (Compost Nos. 11 to 14) a third ventilation pipe was placed about 0.5 m from the floor in the middle of the heap.

Anaerobic (Cold) Composts

These compost heaps were made according to the method of preparing heap of grass silage using 135 μm thick silage grade black polyethylene plastic sheeting obtained from Chemical Industries Limited Canada. Other details on the process, handling of the materials and chemical analyses will be reported elsewhere.

RESULTS AND DISCUSSION

It is understandable that the finished products of the composting with the PR contained higher percent mineral matter than the composts without the rock phosphate (table 3). The "mobile" humus content of the phospho-composts was generally lower than that of the control composts, perhaps partly due to the lower organic contents of the phospho-composts.

In five of the eight pairs of composts, those with PR had slightly lower pH than the controls. This was not obviously related to the type of composting (aerobic vs anaerobic). It appeared that the Ca released from the PR may have been preferentially complexed with humus rather than become an exchangeable cation. It is known that humus, particularly peat humus has a remarkable, albeit limited, capacity for complexing Ca into relatively insoluble coagulates. The absence or low presence of peat, as in Composts numbered 7, 8, 15 and 16, and the extent of solubilization of the PR beyond the capacity of the peat humus to chelate Ca, may have allowed the pH of the phospho-compost (No. 12) to be higher than that of the control (No. 11). Indeed, the following data reveal that in the case of No.12 the solubilization of the PR was the highest.

Table 2A. Formulation of composts, moist weight basis

A. Aerobic

Designation:	Ingredients	Weight (kg)
3 and 4	Farm-yard Manure	1200
	Peat (envelope)	120
5 and 6	Farm-yard Manure	1200
	Peat (mixed and as envelope)	160
11 and 12	Liquid Manure	1800
	Peat (mixed and as envelope)	400
13 and 14	Liquid Manure	2000
	Wood chips	600
	Peat	300
15 and 16	Farm-yard Manure	1000
	Wood chips	610
	Peat	60
	Blood	310

Table 2B. Formulation of composts, moist weight basis

B. Anaerobic

Designation:	Ingredients	Weight (kg)
1 and 2	Farm-yard Manure	2200
	Peat	240
	Water	1740
7 and 8	Farm-yard Manure	1030
	Chopped Barley Straw	110
	Water	730
9 and 10	Liquid Cow Manure	2150
	Peat	240

↑   ↑
−PR   +PR

No.

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16

134

Table 3. Some properties of the composts

No.	Ingredients	pH	% Ash D.M. basis	'Mobile' Humus Index
1	FYM + Peat (An)	6.8	24.5	129
2	FYM + Peat + PR	6.7	37.6	111
3	FYM + Peat (Ae)	6.9	32.5	113
4	FYM + Peat + PR	6.6	35.0	104
5	FYM + Peat (mixed) (Ae)	6.8	34.3	120
6	FYM + Peat + PR	6.7	40.7	89
7	FYM + Straw (An)	7.5	20.8	128
8	FYM + Straw + PR	7.6	31.8	117
9	Liq. Man. + Peat (An)	5.8	15.2	133
10	Liq. Man. + Peat + PR	5.7	22.7	123
11	Liq. Man. + Peat (Ae)	5.0	14.8	119
12	Liq. Man. + Peat + PR	5.2	30.0	110
13	Liq. Man. + Peat + WW (Ae)	5.0	11.6	113
14	Liq. Man. + Peat + WW + PR	4.9	21.6	102
15	FYM + WW + Peat + Bl. (Ae)	6.0	15.3	124
16	FYM + WW + Peat + Bl. + PR	6.2	22.0	86

The various P fractions in the phospho-composts and the extent of PR solubilization in the different systems are given in tables 4 to 11. The H_2O-P fraction was lower in P- enriched composts: this is probably due to the reprecipitation of P by the Ca present in the system while the compost sample were suspended and shaken in water. The 0.1N HCl extractible P is associated with reliable forms of plant available P in organic soils (peats and mucks) which, among soils, resemble the composts most closely. The organic P fraction is obtained through determination of total P with and without ignition. This is a very important fraction, particularly for Ca or Fe- rich soils, as indicated in the introduction. The 2% citric acid (CA) extraction is a standard method for comparing the P-fertilizer value of PR with superphosphate which has a solubility of 80% in 2% CA. The Al-P fraction (P extractible in 0.1M NaOH) is included because the Cargill PR contains some crandallite.

Upon completion in 2 to 4 months, the extent of the total P added by the igneous PR that was solubilized into 'plant available' forms in the various composts was: 37.1% in LM + WW + peat (Ae); 40.2% in FYM + peat (Ae); 47.3% in FYM + S (An); 47.7% in FYM + peat (An); 52.8% in FYM + WW + BI + peat (Ae); 62.8% in LM + peat (An); 63.9% in FYM + peat (Ae); and 74.4% in LM + peat (Ae) (tables 12A and 12B). The average solubilization of the PR by the composting was 53.2%. In all the composts some of the PR can also be substantially solubilized by composting with various wastes.

The extent of solubilization was not dependent on the P content of the composts nor the type of composting, but perhaps on the intensity of the process which in turn was influenced by the properties of the materials used. The details of these aspects will not be discussed here due to the constraints of time and space, as the focus of this presentation is on the feasibility of solubilization of an igneous PR through composting.

With respect to processes responsible for PR solubilization, it is worth mentioning that the aliphatic organic acids (e.g. citric, lactic, succinic), phenols, phenyl carboxylic acids, amino acids, and complex humic and fulvic acids, which all chelate Ca and other metals; mineral acid ions (NO_3, SO_4, CO_3); and heat, all naturally produced during decomposition in immediate vicinity of the PR granules in phospho-composts, dissolve the PR mainly as by partial acidulation treatments. Such solubilization of igneous PR should occur during decomposition of various types of organic materials during properly designed composting.

The peat was of special value as an absorbent for liquid manure and as an insulator for maintaining heat in areas where the night temperature in mid-summer could be below 10°C. Although useful at all times, the peat is not necessary to solubilize PR when dealing with solid wastes. Acidic peat can help curtail loss of N as NH_3 from protein-rich composting materials. However, the same can be achieved by using acidic muck, and wastes from banana, mango and citrus fruits, and, perhaps, some aquatic weeds.

Where commercial composting operations are desirable and feasible, one should look for materials of institutional origins such as urban and municipal garbage, and wastes from barracks, hotels, hospitals, offices, food processing plants, slaughter houses, breweries, forestry and other wood-related operations.

Table 4. Anaerobic farm-yard manure + peat

Fractions of Compost-P	Control (1) ppm-P	Control (1) %	+ RP (2) ppm-P	+ RP (2) %
A. TOTAL	2,210	100	24,705	100
B. H_2O	372	16.8	272	1.1
C. 0.1N HCl	895	40.5	10,811	43.8
D. Organic P	1,103	49.9	1,850	7.5
E. 2% CA	636	28.9	6,517	26.4
F. 0.1M NaOH	23	1.0	18	0.1
C + D + F	2,020	91.4	12,679	51.3
E X 1.25 + D		86.0		40.5

% RP solubilized:

$$\frac{12679 - 2020 \ X \ 100}{24705 - 2210} \qquad = \qquad \underline{47.4}$$

— RP Blank = 37.4

Table 5. Aerobic farm-yard manure + peat

Fractions of Compost-P	Control (3) ppm-P	Control (3) %	+ PR (4) ppm-P	+ PR (4) %
A. TOTAL	2,510	100	23,944	100
B. H_2O	328	13.1	225	0.9
C. 0.1N HCl	751	29.9	12,350	51.6
D. Organic P	993	39.6	3,095	12.9
E. 2% CA	198	7.9	6,322	26.4
F. 0.1M NaOH	32	1.3	36	0.15
C + D + F	1,776	70.7	15,481	64.6
E X 1.25 + D		49.4	10,998	45.9

% RP solubilized:

$$\frac{15481 - 1776 \ X \ 100}{23944 - 2510} \qquad = \qquad \underline{63.9}$$

— RP Blank = 53.9

Table 6. Aerobic farm-yard manure + peat (mixture)

Fractions of Compost-P	Control (5)		+ RP (6)	
	ppm-P	%	ppm-P	%
A. TOTAL	3,306	100	35,099	100
B. H_2O	344	9.6	259	0.74
C. 0.1N HCl	1,427	43.1	11,349	32.3
D. Organic P	973	29.4	3,827	10.9
E. 2% CA	924	27.9	6,434	18.3
F. 0.1M NaOH	26	0.8	23	0.07
C + D + F	2,426	73.4	15,199	43.3
E X 1.25 + D	2,128	64.4		33.8

% RP solubilized:

$$\frac{15199 - 2426 \; X \; 100}{35099 - 3306} \quad = \quad \underline{40.2}$$

$$-\!-\; RP \; Blank \qquad = \qquad 30.2$$

Table 7. Aerobic farm-yard manure + straw

Fractions of Compost-P	Control (7)		+ RP (8)	
	ppm-P	%	ppm-P	%
A. TOTAL	3,688	100	21,406	100
B. H_2O	517	14.0	394	1.8
C. 0.1N HCl	1,927	52.2	7,682	35.9
D. Organic P	1,045	28.3	3,671	17.1
E. 2% CA	1,124	30.5	4,793	22.4
F. 0.1M NaOH	23	0.6	21	0.1
C + D + F	2,995	81.1	11,774	53.1
E X 1.25 + D	2,450	66.4	9,662	45.1

% RP solubilized:

$$\frac{11374 - 2995 \; X \; 100}{21406 - 3688} \quad = \quad \underline{47.3}$$

$$-\!-\; RP \; Blank \qquad = \qquad 37.3$$

Table 8. Anaerobic liquid manure + peat

Fractions of Compost-P	Control (9) ppm-P	%	+ RP (10) ppm-P	%
A. TOTAL	3,762	100	16,586	100
B. H_2O	1,544	41.0	1,463	8.8
C. 0.1N HCl	2,642	70.2	10,909	65.7
D. Organic P	556	14.8	341	2.1
E. 2% CA	2,899	77.0	7,578	45.7
F. 0.1M NaOH	28	0.8	34	0.2
C + D + F	3,226	85.6	11,284	68.0
E X 1.25 + D		110.8		59.2

% RP solubilized:

$$\frac{11284 - 3226 \times 100}{16586 - 3762} = \underline{62.8}$$

—— RP Blank = 52.8

Table 9. Aerobic liquid manure + peat

Fractions of Compost-P	Control (11) ppm-P	%	+ RP (12) ppm-P	%
A. TOTAL	3,537	100	31,411	100
B. H_2O	1,903	53.8	1,538	4.9
C. 0.1N HCl	2,394	67.7	14,360	45.7
D. Organic P	794	22.4	9,567	30.5
E. 2% CA	1,450	41.0	10,360	33.0
F. 0.1M NaOH	50	1.4	38	0.12
C + D + F	3,238	91.6	23,965	76.3
E X 1.25 + D	2,606	73.7	22,517	71.7

% RP solubilized:

$$\frac{23965 - 3238 \times 100}{31411 - 3537} = \underline{74.4}$$

—— RP Blank = 64.4

Table 10. Aerobic liquid manure + peat + wood waste

Fractions of Compost-P	Control (13)		+ RP (14)	
	ppm-P	%	ppm-P	%
A. TOTAL	3,181	100	26,103	100
B. H_2O	1,650	51.9	1,368	5.2
C. 0.1N HCl	2,312	72.7	9,310	35.7
D. Organic P	619	19.4	2,138	8.2
E. 2% CA	1,480	46.5	9,076	34.7
F. 0.1M NaOH	36	1.13	23	0.08
C + D + F	2,967	93.3	11,471	43.9
E X 1.25 + D	2,469	77.6	13,483	51.6

% RP solubilized:

$$\frac{11471 - 2967 \; X \; 100}{26103 - 3181} = 37.1$$

— RP Blank = 27.1

Table 11. Aerobic wood waste + FYM + peat + blood

Fractions of Compost-P	Control (15)		+ RP (16)	
	ppm-P	%	ppm-P	%
A. TOTAL	1,376	100	15,794	100
B. H_2O	198	14.4	184	1.2
C. 0.1N HCl	516	37.5	8,402	53.2
D. Organic P	623	45.3	355	2.2
E. 2% CA	266	19.3	5,940	37.6
F. 0.1M NaOH	20	1.4	16	0.1
C + D + F	1,159	84.2	8,773	55.5
E X 1.25 + D	956	69.4	7,780	49.2

% RP solubilized:

$$\frac{8773 - 1159 \; X \; 100}{15494 - 1376} = 52.8$$

— RP Blank = 42.8

Table 12A. Summary - Aerobic

COMPOSTS	Total P %	Soluble P %	Soluble P % of total	RP Soluble %
3. FYM + Peat	0.25	0.18	70.7	
4. FYM + Peat + PR	2.39	1.55	64.6	63.9
5. FYM + Peat (Mixed)	0.33	0.24	73.4	
6. FYM + Peat (Mixed) + PR	3.51	1.52	43.3	40.2
11. Liquid Manure + Peat	0.35	0.32	91.6	
12. Liq. Man. + Peat + PR	3.14	2.40	76.3	74.4
13. Liq. Man. + Peat + WW	0.32	0.30	93.3	
14. Liq. Man. + Peat + WW + PR	2.61	1.15	43.9	37.1
15. Liq. Man. + Peat + WW + Bl.	0.14	0.12	84.2	
16. Liq. Man. + Peat + WW + Bl. + PR	1.58	0.88	55.5	52.8

Average % RP solubilization: 53.7

Table 12B. Summary - Anaerobic

COMPOSTS	Total P %	Soluble P %	Soluble P % of Total	RP Soluble %
1. FYM + Peat	0.22	0.20	91.4	
2. FYM + Peat + PR	2.47	1.26	51.3	47.4
7. FYM + Straw	0.37	0.30	81.2	
8. FYM + Straw + PR	2.14	1.14	53.1	47.3
9. Liquid Manure + Peat	0.38	0.32	85.8	
0. Liq. Man. + Peat + PR	1.66	1.13	68.0	62.8

Average % RP solubilization: 52.5

CONCLUSION

This study has shown that composting can substantially solubilize igneous PR into 'plant-available-P' forms, and thus increase the fertilizer value of the PR many times, especially for soils where the efficiency of P fertilization is low.

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