

## Short-term Effect of Phosphogypsum on Soil Chemical Properties

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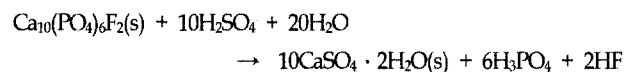
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**Abstract** : Short-term effect of phosphogypsum on soil properties including acidification, salinity and metal availability were investigated under laboratory and field conditions. Phosphogypsum and mixtures of phosphogypsum and compost were added to soil and incubated in a laboratory condition with 15% moisture content. Phosphogypsum treatments were 2.5 and 5.0 g/kg soil and in the treatments of phosphogypsum and compost mixture 10 g of compost was added additionally. After the 30 days of incubation, an additional phosphogypsum and/or compost were added to the remaining soils at the same rates of the first treatments. pH, electrical conductivity, and available hazardous elements were measured periodically during the incubation. Field experiment was conducted in a plastic film house of melloon with four treatments of phosphogypsum and compost mixtures - 25+125, 50+125, 50+250 and 100+250 kg/165 m<sup>2</sup>. pH, electrical conductivity, and hazardous elements in soil and total hazardous elements in leaf were measured. In the laboratory experiment, after 30 days of the first phosphogypsum application, soil pHs were lowered by 0.7-0.8 units. After the second treatment of phosphogypsum 0.2 units of additional acidification occurred. However, acidification was not observed in the soils treated with mixtures of phosphogypsum and compost. In the laboratory experiment, phosphogypsum treatments increased electrical conductivity very significantly. In field experiment, pH and electrical conductivity of soils treated with phosphogypsum were nearly the same as those of soil not treated with phosphogypsum. Since soil condition in the field study was an open system, the free acids and salts derived from phosphogypsum could be diffused down with water leaching through the soil profile and then any significant acidification or salt accumulation in the topsoil could not be observed. In both laboratory and field experiments, levels of available hazardous elements in soils treated with phosphogypsum were quite low and not different from the levels found in the control soil. Results obtained from this study suggest that application of phosphogypsum at appropriate rates on agricultural land appears of no concern in terms of acidity, salinity and hazardous element content of soil.

**Key words** : phosphogypsum, acidity, electrical conductivity, heavy metal, hazardous element

### INTRODUCTION

The phosphate fertilizer industry has been the most significant producer of by-product gypsum. The mineral fluoroapatite is treated with sulfuric acid to produce phosphoric acid in the following wet-process acidulation :



The phosphoric acid is used to manufacture high-analysis P

fertilizers, while the by-product gypsum is collected as a waste product. The stoichiometry and masses involved in the reaction result in production of hydrated CaSO<sub>4</sub> in amounts equal to 1.0~1.5 times the mass of fluoroapatite reacted. This fine-grained, high-purity material, termed phosphogypsum, is produced in large quantities in world-wide, and presents a serious disposal problem<sup>1)</sup>.

The increased environmental awareness of the past decades has placed a greater emphasis on waste recycling, and enormous efforts are being made to spend phosphogypsum in established markets such as cement additives, wallboard manufacture, and traditional agricultural uses<sup>1,2)</sup>. Phosphogypsum is typically 85~95% gypsum; the major impurity is residual quartz sand (SiO<sub>2</sub>), which may range from 3~17%. Residual P

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and F may make up 0.1-1.0% of phosphogypsum as well. The material is typically acidic (pH 4.5-5.5) due to free acid remaining in the pore fluids, but it is not strongly buffered.

Agronomic use of phosphogypsum is highly desirable from the point of view of recycling by-product and eliminating the need for stockpiling. So far phosphogypsum has been known as a very effective soil amendment in the amelioration of acidic subsoil and dispersive soils.

Subsoil acidity is one of the major yield-limiting factors in acid soils because it restricts root growth. Shainberg et al. and Sumner have been reviewed the use of phosphogypsum to ameliorate subsoil acidity of soils around the world<sup>3,4</sup>. Lime is totally ineffective in supplying Ca to subsoils due to its insolubility in limed topsoils. Gypsum, however, continually dissolves to move  $\text{Ca}^{2+}$  with percolating water into subsoil horizons. In a long-term experiments with gypsum incorporated into the topsoil, exchangeable Ca and  $\text{SO}_4$  were higher down the soil profile in the gypsum than in the control treatment and complementary reduction in exchangeable Al was observed<sup>5</sup>.

Gypsum has been used for remediation of sodic soils for some time, acting largely to replace exchangeable Na with Ca; it also has a marked effect on non-sodic, dispersive soils by supply electrolyte to the soil solution. Results summarized by Shainberg et al. indicate that gypsum applied on the soils surface prior to rainfall significantly increases infiltration rate, total infiltrated water, and reduces soil erosion<sup>3</sup>.

Several observations have suggested surface-applied gypsum may be effective in reducing crust strength and increasing emergence on dispersive soils<sup>6,7</sup>. Further work by Shanmugathan and Oades has confirmed the positive effect of gypsum on emergence, and shown the importance of reducing clay dispersion in establishing good crop stands<sup>8</sup>.

Potential environmental concerns are an important consideration in suggesting any material as a soil amendment, particularly a waste or by-product such as phosphogypsum<sup>9</sup>. While the major constituents (Ca and  $\text{SO}_4$ ) are not likely to be considered environmentally damaging in soils and ground or surface waters, phosphogypsum may contains free acidity, radioactive elements and metals, carried over from the primary processing. The US EPA has restricted some use of phosphogypsum in Florida due to trace contamination with radioactive elements, principally  $^{236}\text{Ra}$  and  $^{222}\text{Rn}$ , which are highly toxic. Contamination levels in rock phosphates are quite different depending on the mining sites, and phosphogypsum produced from the rock phosphate which contain little amount of metals or radioactive elements can be recycled as a soil

**Table 1. Selected physicochemical properties of soil used in the laboratory incubation experiment**

pH	OM	CEC	Sand	Silt	Clay	Texture
	%	cmol/kg	-----	%	-----	
5.2	2.3	17.8	31.3	44.3	24.4	Loam

amendment. Namhae Chemical Co. has about 16,000,000 ton of phosphogypsum in stacks that cover 131 acres and range up to 35 m tall. The main commercial use of the phosphogypsum is for wallboard and as a cement additive, but agronomic uses of the material is prohibited for fear of the potential contaminations of soil.

In this study, short-term effect of phosphogypsum on soil properties including acidification, salinity and metal availability were investigated under laboratory and field conditions.

## MATERIALS AND METHODS

### pH Buffering of Phosphogypsum

pH buffering of phosphogypsum was determined by titration of 10 g of phosphogypsum in 50 mL of  $\text{H}_2\text{O}$  with solid  $\text{Ca}(\text{OH})_2$  to approximately pH 7.0 while vigorously stirring, and Al, Fe,  $\text{PO}_4$ , and  $\text{SO}_4$  in the suspension were determined using a Varian Liberty Series II (Mulgrave, Australia) inductively coupled argon plasma emission spectrometry (ICP-ES) and ion chromatography (Dionex 150 model, Sunnyvale, CA).

### Laboratory Incubation Experiment

A loam soil from the experimental farm of Taegu University was air-dried and passed through a 5-mm sieve. Selected physicochemical properties of the soil were described in Table 1. Phosphogypsum used in this experiment was obtained from Namhae Chemical Co., and the general properties were described in Table 2. Application rates of phosphogypsum were 2.5 and 5.0 g/kg soil. In addition to the phosphogypsum treatments, soils treated with mixtures of phosphogypsum and compost (1:4 and 1:2) were included in the experiment. The details of treatments were described in Table 3.

Treated soils contained in plastic bags were mixed thoroughly by hand, and the gravimetric moisture content was adjusted to 15% which corresponds to 60% of soil water holding capacity. Treated soil samples were incubated under laboratory condition, and water lost by evaporation was replenished

**Table 2. Total analysis of phosphogypsum of Namhae Chemical Co.**

pH	CaSO <sub>4</sub> · 2H <sub>2</sub> O	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	SO <sub>3</sub>	As	Cd	Cr	Cu	Hg	Pb
----- % -----						----- mg/kg -----						
2.5-5.5	>93	2.3-4.5	0.7-1.6	0.1-1.6	29-30	43-44	1-18	<2	<5	<5	<1	10-40

\* Data obtained from Namhae Chemical Co.

**Table 3. Treatments of phosphogypsum and saw dust compost in the laboratory incubation experiment**

Treatments	Application rate, g/kg soil	
	Phosphogypsum	Saw dust compost
1	-	-
2	-	10.0
3	2.5	-
4	5.0	-
5	2.5	10.0
6	5.0	10.0

every week during the experiment. Each treatment was run in triplicate for time intervals ranging between 1 and 30 days, and pH, electrical conductivity, and available metals were measured periodically using sub soil samples.

After the 30 days of incubation, an additional phosphogypsum and/or compost were treated to the remaining soils at the same rates of the first treatments. And the same measurements were undertaken for another 30 days.

### Field Experiment

To investigate the short-term effects of phosphogypsum on soil properties and element uptake by plant, a field study was begun in a plastic film house in Sungju, Kyongbuk on 1 December in 2000 by establishing a completely randomized design of five treatments (Table 4). Each treatment plot was 165 m<sup>2</sup>. Mixtures of phosphogypsum and compost were piled and spread to the soil surface and tilled in with a rototiller. The same phosphogypsum and compost as those used in the laboratory experiment were used. Fertilization and other managements of the house were followed by the conventional methods. Mellon seedlings were transplanted on 10 January in 2001.

Soil samples were collected before the treatment and on 25 July in 2001. Soil samples were air-dried and passed through a

**Table 4. Treatments of mixtures of phosphogypsum and saw dust compost in the field experiment**

Treatments	Application rate, kg/165 m <sup>2</sup>	
	Phosphogypsum	Saw dust compost
1	-	125
2	50	250
3	100	250
4	25	125
5	50	125

2-mm sieve, and leaf samples were collected on 16 February and on 25 July in 2001 and dried at 60°C. pH, electrical conductivity, and available nutrient and metal contents in soil and total content of metal in leaf were measured.

### Analytical Methods

Soil pH was determined using 1:5 soil/water suspension with a combination glass electrode. After pH measurement the suspension was filtered using Whatman No. 42 filter paper, and electrical conductivity was determined using the filtrate with a conductivity meter (Check mate 90 Model, Corning, NY). Available metals were extracted using 0.005 M DTPA solution (pH 7.3) containing 0.01 M CaCl<sub>2</sub> and 0.1 M triethanolamine<sup>10</sup>, and measured by a Varian Liberty Series II (Mulgrave, Australia) inductively coupled argon plasma emission spectrometry (ICP-ES). Total metal concentration in leaf samples was determined after H<sub>2</sub>SO<sub>4</sub>-H<sub>2</sub>O<sub>2</sub> digestion using ICP-ES<sup>11</sup>.

## RESULTS AND DISCUSSION

### Soil pH

Phosphogypsum contains free acids in the pore fluids and continuous applications of this material in agricultural lands is expected to acidify surface soil to some extent. This may be

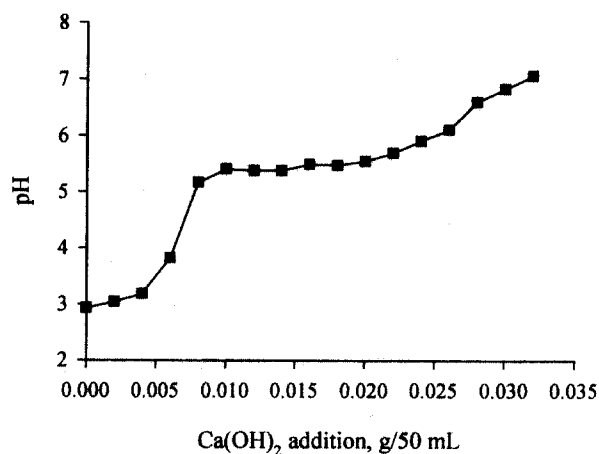


Fig. 1. Titration of 10 g/50 mL water suspension of phosphogypsum with solid  $\text{Ca}(\text{OH})_2$ .

one of the limiting factors in recycling of phosphogypsum as a soil amendment. However, since the acidity of phosphogypsum is not strongly buffered, considering the strong buffering capacity of natural soil systems, such acidification is expected not to be very significant.

Water suspension of phosphogypsum was titrated with solid  $\text{Ca}(\text{OH})_2$  and the characteristics of acidity of phosphogypsum was shown in Fig. 1. Buffering occurred at pH around 3.0 is mostly due to the free sulfuric acid contained in phosphogypsum. The next buffer region seems to be due to the iron, and the other strong buffering at pH around 5.5 is due to Al in phosphogypsum. Aluminum and iron concentrations in the suspension of phosphogypsum used for the titration were 2.62 and 0.12 mg/L, respectively. Buffering with the precipitation of  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  hydroxides is known to be observed at pH 4.4 and 5.4<sup>12)</sup>. Acidity due to the free acids in phosphogypsum was about 1.3 cmol/kg and total acidity of phosphogypsum titrated to pH 6.5 was about 3.6 cmol/kg. Acidity of phosphogypsum due to the free acid was small and not strongly buffered, and also the acidity due to  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  was not very strong but would be more important than free acids in acidification of soils. For soils which have about 2% organic matter, the buffering intensity of the soils could be values in the range 0.2-30 cmol/kg/pH at around pH 5.0<sup>13)</sup>. Therefore, when a relatively small amount of phosphogypsum (<5 g/kg) is incorporated in soil, the acidity of phosphogypsum is regarded as insignificant in soil acidification.

pH changes in soils amended with phosphogypsum during the laboratory incubation were shown in Fig. 2. After 30 days of the first phosphogypsum application, soil pH were lowered

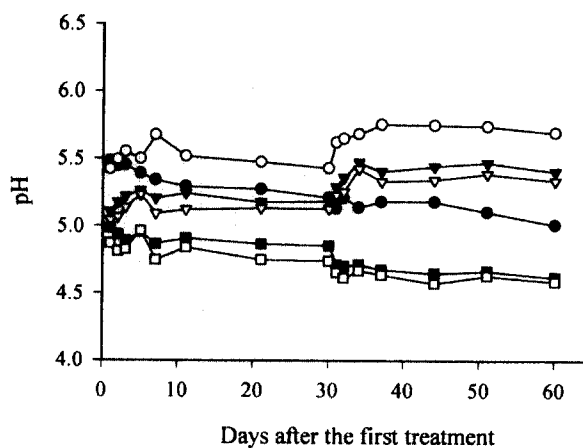


Fig. 2. pH changes of soils treated with phosphogypsum and/or compost during the laboratory incubation experiment.

●: control, ○: compost 10 g/kg, ▼: phosphogypsum 2.5 g + compost 10 g/kg, ▽: phosphogypsum 5.0 g + compost 10 g/kg, ■: phosphogypsum 2.5 g/kg, □: phosphogypsum 5.0 g/kg.

by 0.7-0.8 units. During the first several days very rapid decrease of soil pH was observed. The slow decrease of pH in the later period was small and similar to the acidification in the soil of control treatment. After the second treatment of phosphogypsum about 0.2 units of additional acidification occurred. Considering the acidification of 0.5 units in the control soil, net soil acidification with phosphogypsum treatments was about 0.4 units.

In the soil of compost treatment at the rate of 10 g/kg, pH was increased by about 0.2 units and then lowered to the initial soil pH later. After the second treatment of compost, pH was increased by 0.3 units. pH increase was more significant in the second application of compost than that in the first application.

In the soils treated with mixtures of phosphogypsum and compost, at the first day of the incubation pH decreased rapidly by about 0.3 units but increase of 0.2-unit pH occurred in a week. And more significant soil pH increase was observed after the second application of the mixture and in the end of the incubation pH was nearly the same as the initial soil pH.

The rapid decrease of pH in the treatments including phosphogypsum seems to be the effect of free acids and salts contained in phosphogypsum. In addition to the free acids and salts contained in phosphogypsum, reactions between gyp-

**Table 5. pH, EC and extractable nutrient concentration in the soil of plastic film house**

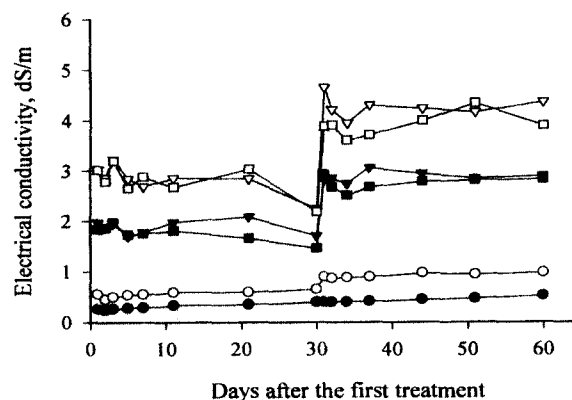
Sampling Date	Treatment*	pH	EC	mg/kg						
				P <sub>2</sub> O <sub>5</sub>	NO <sub>3</sub> -N	NH <sub>4</sub> -N	Ca	K	Mg	Na
16 Feb. 2001	1	7.3	5.2	120.2	42.5	3.2	16.8	1.4	3.9	0.5
	2	7.4	5.6	120.5	48.2	3.3	18.8	1.2	4.0	0.6
	3	7.5	5.9	146.6	43.7	3.0	18.8	1.4	4.0	0.4
	4	7.5	5.3	122.1	38.1	2.6	20.7	1.6	3.9	0.6
	5	7.4	5.7	141.6	36.9	3.0	26.9	1.5	4.2	0.8
25 Jul. 2001	1	6.8	5.3	92.5	84.2	6.3	17.2	3.9	4.2	0.7
	2	6.6	9.6	100.7	83.1	9.1	20.3	5.1	5.6	1.1
	3	7.0	7.0	107.2	73.4	9.7	32.4	6.7	6.8	1.2
	4	6.9	4.9	78.0	90.9	5.8	18.5	3.8	3.5	0.8
	5	6.6	7.7	109.9	82.7	7.1	20.7	5.0	4.8	0.7

\* Refer table 4 for details of the treatments.

sum and soil surfaces, in which Ca replaces H and Al (which hydrolyzes to give H<sup>+</sup>) and SO<sub>4</sub> replaces OH by ligand exchange, can affect soil pH. The resultant pH measured will thus depend on the extents of the two reactions in any particular case. Pavan et al. showed that, in soils high in exchangeable Al, H<sup>+</sup> release by hydrolysis was likely to exceed OH<sup>-</sup> release, causing soil pH to decrease<sup>14</sup>). In this study such redistribution of ions in soil was not examined in detail, but ion exchange phenomenon should be further investigated to understand the effect of gypsum on soil acidity. Although phosphogypsum application on agricultural lands can cause soil acidification, application with compost is expected to eliminate such acidification effect. Also the incubation study was undertaken under a closed system and then the acidification effect was observed significant. But the effect could be much small in open systems.

Soil pH changes in a field experiment were shown in Table 5. Differences in soil pH among the treatments were not significant, and pHs of soil treated with phosphogypsum were nearly the same as the pH of control soil. Since phosphogypsum was treated with compost, the buffer action of compost could eliminate the acidification effect of phosphogypsum which was significant in the laboratory experiment. Also soil condition in the field study was an open system, free acids and salts contained in phosphogypsum could be diffused down with water leaching through the soil profile and then acidification of top soil could not be observed.

Therefore, although phosphogypsum itself has a potential for acidification of soil, it is relatively small and can be well



**Fig. 3. Electrical conductivity changes of soils treated with phosphogypsum and/or compost during the laboratory incubation experiment.**

●: control, ○: compost 10 g/kg, ▼: phosphogypsum 2.5 g + compost 10 g/kg, ▽: phosphogypsum 5.0 g + compost 10 g/kg, ■: phosphogypsum 2.5 g/kg, □: phosphogypsum 5.0 g/kg.

buffered if we use phosphogypsum in agricultural lands with composts together.

### Soil EC

According to Keren and Shainberg<sup>15</sup>, the rate of dissolution of phosphogypsum can be 10 fold greater than that of mined gypsum. Phosphogypsum of acidic pH (2-3) can also have much more soluble salts than the pure gypsum. In general, the electrolyte concentrations for phosphogypsum are about 3 times greater than for mined gypsum at application rates less than 5 ton/ha<sup>16</sup>). Excess soluble salt content in phosphogypsum is one of the factors which have hindered agricultural use of the

material.

Soil EC changes during the laboratory incubation were shown in Fig. 3. As described in the section of materials and methods, soil EC values were measured in 1:5 water extract and the dilution factor was not adjusted. In the control and compost treatments, ECs were in the range of 0.2-1.0 dS/m. However, EC was significantly higher in soils of those treatments including phosphogypsum. After the second treatment of phosphogypsum, ECs were about 2.9 and 4.2 dS/m in the soils of 2.5 and 5 g/kg of phosphogypsum applications, respectively. The effect of compost on soil EC was relatively small comparing to phosphogypsum, and ECs in soils of phosphogypsum only and phosphogypsum and compost treatments were nearly the same.

This incubation study was undertaken under a closed system and then the effect of phosphogypsum on soil EC was observed very significant. In most of soils, soluble salt concentrations increased after gypsum treatments, and a very subdued increase in soluble Ca, SO<sub>4</sub>, Al, Mn, Cl, F levels and total electrolyte concentration was found in closed pots with direct addition of gypsum and no leaching<sup>3</sup>). Considering the results of incubation study, potential hazard of phosphogypsum in view of salt accumulation could be serious under continuous applications of this material to agricultural lands. But in open systems the effect is expected to be much small. Soil EC changes in a field experiment were shown in Table 5, and the values were in the range of 6.6-7.5 dS/m. The soil has been used for melon continuously during the last 6 years and was under saline condition. Differences in soil EC among the

treatments were not significant, and ECs of soil treated with phosphogypsum were nearly the same as the EC of soil not treated. Since soil condition in the field study was an open system, the salts derived from phosphogypsum could be diffused down with water leaching through the soil profile and then any significant salt accumulation in the topsoil could not be observed.

The results of many experiments conducted in Georgia and elsewhere have shown substantial yield responses to the surface incorporation of 3-4 tons/A of gypsum after sufficient time has elapsed to allow the gypsum to dissolve and move into the subsoil<sup>3,4</sup>). The assumption that gypsum dissolution was sufficiently rapid to maintain a saturated gypsum solution was reasonable in the reclamation models for dispersive soils. But, because of its limited solubility (0.2%), gypsum presents no salt hazard to plants when applied in reasonable quantities.

Therefore, although phosphogypsum itself has a potential for salt accumulation in soil, but in field conditions it is insignificant and can be totally eliminated by application of reasonable quantities and a proper water management in agricultural lands. Greater care should be exercised in the use of heavy applications of gypsum on very sandy soil. Rather than the salt problem, large quantities of soluble Ca from the gypsum can cause severe nutritional problems with Mg and K<sup>14</sup>).

### Contaminant Elements

Generally phosphogypsum is quite pure, with some residual quartz and/or clay material entrained after processing, and contaminant metals are typically quite low. Analysis of gypsum

**Table 6. Effect of phosphogypsum on concentrations of available contaminant elements in soils of the laboratory incubation experiment**

Treatment	After the first incubation					After the second incubation				
	As	Cd	Cr	Cu	Pb	As	Cd	Cr	Cu	Pb
	----- mg/kg -----									
1	1.40	0.01	0.21	1.08	0.78	1.20	tr	0.25	1.09	1.12
2	0.52	tr	0.23	1.04	0.88	0.49	tr	0.21	1.09	0.85
3	1.31	tr	0.21	0.97	1.01	0.38	tr	tr	0.81	0.60
4	1.12	tr	0.19	0.94	0.94	0.17	tr	tr	0.76	0.60
5	0.73	tr	0.26	0.98	0.78	0.34	tr	0.17	0.95	0.57
6	0.64	tr	0.23	0.94	0.62	0.50	tr	tr	0.80	0.78

\* Refer table 3 for details of the treatments.

\*\* tr : trace.

materials including phosphogypsum have been summarized by Miller et al.<sup>17)</sup>. Phosphogypsum from Florida contained 2-8 mg/kg of As, 3-6 mg/kg of Cd, 2-12 mg/kg of Pb and 0.5-2 mg/kg of Se. And chemical composition of the phosphogypsum from Namhae Chemical Co. are presented in Table 2. Phosphogypsum of Namhae Chemical Co. contains much higher amount of Pb than Florida phosphogypsum. Average metal contents in phosphogypsum of Namhae Chemical Co. were much lower than those in composts of municipal sewage sludge<sup>18)</sup>.

When phosphogypsum is considered as a soil amendment, contamination of soils with heavy metals and other trace elements is possible, and such possibility of hazardous element contamination has hindered agricultural use of the material.

Amounts of available contaminant elements in soil treated with phosphogypsum were presented in Table 6 and 7. Levels of available contaminant elements in the soil treated with phosphogypsum were quite low, and not different from the levels found in the control soil both in the laboratory and field experiments. Ha et al. also found that application of the mixture of fly ash and phosphogypsum in agricultural land did not increase the levels of available heavy metals in soil<sup>19)</sup>. Recovery of contaminant elements in leaf of melloon was presented in Table 7. Concentrations of contaminant elements in the leaf of melloon were not significantly different among the treatments. And the levels were relatively lower comparing to the levels in crops grown in soils treated with fly ash or composts

of municipal sewage sludge<sup>18,19)</sup>. Although rock phosphate, particularly from Florida, often contains substantial quantities of Cd, this Cd appeared to be of no concern environmentally in terms of the content in grain, being only a fraction of values reported in situations where Cd has been added to soil as municipal sludges or as phosphate fertilizers<sup>20,21)</sup>. Therefore phosphogypsum should present no environmental problems in terms of contaminant elements when used at appropriate rates for agricultural purposes.

## CONCLUSIONS

World-wide production of phosphogypsum is estimated at 150 million ton annually. Agricultural uses have the potential to use a considerable amount of this stockpile. Obviously, no wide-spread use of by-product gypsums will be made unless such uses pose no threat to the public health and soil contaminations.

In addition to supplying the essential elements, Ca 23% and sulfur 17%, gypsum can have profound effects on both the physical and chemical properties of certain soils. Such soils frequently have one or more of the following characteristics : 1) dispersive topsoils which readily form crusts, or 2) subsoil hardpans which limit root penetration or 3) acid subsoils in which high levels of soluble aluminum and low levels of Ca prevent root proliferation.

Results obtained from this study suggest that application of

**Table 7. Effect of phosphogypsum on concentrations of available contaminant elements in soil of plastic film house and recovery in melloon leaf**

Sampling Date	Treatment*	Concentrations in soil					Concentrations in melloon leaf				
		As	Cd	Cr	Cu	Pb	As	Cd	Cr	Cu	Pb
		mg/kg									
16 Feb. 2001	1	tr	tr	tr	1.59	1.31	0.67	1.49	3.24	6.29	1.68
	2	0.52	tr	tr	1.25	1.79	0.49	0.92	2.12	6.93	3.67
	3	tr	tr	tr	1.29	1.34	0.35	1.97	0.97	9.01	1.10
	4	tr	tr	tr	1.46	1.25	0.96	1.03	1.73	7.07	1.58
	5	0.05	tr	tr	1.23	1.21	0.45	1.60	1.20	8.73	1.45
25 Jul. 2001	1	tr	tr	tr	1.23	1.02	0.54	1.33	3.63	8.03	tr
	2	0.15	tr	tr	1.06	1.29	0.37	0.68	2.01	8.84	1.19
	3	0.79	tr	tr	1.22	1.26	0.42	1.83	2.95	7.85	2.31
	4	0.89	tr	tr	1.25	1.28	0.58	0.72	2.28	8.56	0.57
	5	0.79	tr	tr	1.03	1.39	0.61	0.57	2.50	7.06	1.70

\* Refer table 4 for details of the treatments.

\*\* tr : trace.

phosphogypsum at appropriate rates on agricultural land appears of no concern in terms of acidity, salinity and hazardous element content of soil. However, further investigations should be undertaken to resolve any other environmental and agronomic questions that remain to be answered before large-scale land application of phosphogypsum can be initiated.

## ACKNOWLEDGEMENT

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