VEGETATION ESTABLISHMENT ON PHOSPHOGYPSUM IN FLORIDA: EFFECTS OF SOIL AMENDMENTS[1]

by

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Abstract. Phosphogypsum (PG) is a by-product of phosphate fertilizer production,and more than 600 million tons have accumulated on 5,000 plus acres in Florida. This paper examines the use of several soil amendments to enhance vegetation establishment on phosphogypsum from an inactive "stack" (pH near 5.0). A greenhouse study demonstrated that the PG was deficient in potassium and magnesium, as well as nitrogen. In a field study, tilling-in dolomitic limestone (1.0 ton/acre), sand tailings (2 inches) and overburden (2 inches) enhanced plant growth the first season, while composted garbage (2 inches) inhibited plant growth. By the third growing season, neither plant production nor ground cover differed among the treatments and the control. However, species composition did vary. Bermudagrass *(Cynodon dactylon)* dominated the control, dolomite treated, and sand tailings treated plots. Weeping lovegrass *(Eragrostis curvula)* dominated the composted garbage plots. There was a fairly even mixture of bermudagrass, weeping lovegrass, and bahiagrass *(Paspalum notatum)* on the overburden amended plots.

INTRODUCTION

Phosphogypsum is a by-product of phosphoric acid production. For each ton of P_2O_5 produced, approximately five tons of phosphogypsum must be stockpiled or disposed. To date, more than 600 million tons have accumulated in Florida on 5000 plus acres, and phosphogypsum is continuing to accumulate at the rate of over 30 million tons per year.

After phosphate rock has been reacted with sulfuric acid to produce phosphoric acid, the precipitated gypsum is removed on filters and is pumped in slurry form to an impoundment where it is allowed to settle. As the gypsum accumulates, a small dragline removes some of the gypsum for raising the height of the dikes. By this process the gypsum settling impoundment, or "stack" as it is often called, increases in elevation. As a stack grows in height (up to 200 feet) the area of the settling impoundment decreases until a point is reached where the pond capacity becomes too small and the pumping height requires too much energy.

When phosphogypsum stacks reach the end of their useful lives they must be closed and reclaimed. An important component of any reclamation plan will

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include a vegetative cover. A cover of vegetation is desirable for aesthetic reasons, to reduce erosion and improve the quality of surface runoff water, and to allow beneficial use of the land such as for wildlife habitat.

There are several problems associated with establishing vegetative cover on phosphogypsum. They are: (1) the residual acidity, (2) nutrient deficiencies and low nutrient-holding capacity, and (3) the tendency for caking and crust formation.

The primary problem with phosphogypsum is its acidity. May and Sweeney (1980) observed pH values usually in the range of two to three in numerous samples, although samples from older, more weathered stacks had slightly higher pH values near four. Bromwell and Carrier, Inc. (1989) reported a pH of 5.1 in a sample of phosphogypsum from an older, inactive stack. Phosphogypsum is comprised primarily of the slightly soluble neutral salt, calcium sulfate dihydrate. The acidity is due mainly to residual phosphoric and sulfuric acids, although hydrofluoric and fluosilicic acids are also formed during processing (Smith and Wrench 1984).

Preliminary laboratory and greenhouse studies, plus field observations, indicated that plants could grow on phosphogypsum if the pH was raised to 4.0 or greater (Richardson 1992). Dolomitic limestone and phosphatic clay were effective neutralizing agents, while leaching with water was also an effective mechanism for reducing acidity. Leaching with rainwater is probably responsible for the higher pH values (4.7 to 5.3) found at the surface of older, inactive phosphogypsum stacks than on active, acid-laced phosphogypsum stacks.

Although phosphogypsum has been studied as a calcium or sulfur fertilizer (Baird and Kamprath 1981, Mullins and Mitchell 1990, Hunter 1989) little is known about its nutritional status in relation to serving as a plant growth medium. A sample of weathered phosphogypsum analyzed for extractable nutrients by Bromwell and Carrier, Inc. (1989) indicated adequate phosphorus but very low magnesium and potassium levels. Several micronutrients were also low in concentration.

Chang et al., (1989) have found that phosphogypsum, when compacted, can form a high strength material suitable for roadbeds. We have observed that moistened phosphogypsum, upon drying, forms a crust that is quite resistant to penetration. We have also observed that the root systems of plants that have become naturally established on weathered phosphogypsum are often very shallow, and the plants are easily uprooted.

One method of coping with the chemical and physical properties of phosphogypsum is to cover it with overburden or soil. However, the question then arises as to how deep the soil or overburden cover must be to support an adequate vegetative cover. The deeper the soil cover, the more costly are the earthmoving operations and the greater are the impacts on soil borrow areas. This study is part of a research program to develop effective, but lower cost, methods of establishing vegetation on phosphogypsum stacks when they are closed. The use of soil amendments in modest amounts is one approach that might eliminate or reduce the need for overburden or soil cover, especially on weathered phosphogypsum.

Several materials are available in Florida that may modify the chemical and physical characteristics of phosphogypsum and improve its ability to support plant growth. Potentially useful soil amendments include dolomitic limestone; municipal wastes such as composted garbage or sewage sludge; and mining wastes such as overburden, sand tailings, or phosphatic clay. During beneficiation (washing and upgrading) of the phosphate ore, phosphatic clay and sand tailings are removed in separate steps.

METHODS

Greenhouse Study.

Chemical analysis of phosphogypsum indicated that the older, weathered material could be deficient in potassium, magnesium and some micronutrients. To test this, phosphogypsum from an "inactive" stack (U.S. Agri-Chemicals' Bartow stack) was treated with various nutrient solutions in a greenhouse pot study. Several soil amendments were also tested for their abilities to supply critical nutrients.

Six-inch diameter by six-inch deep pots were each filled with 2.5 kg of phosphogypsum or 2.0 kg phosphogypsum plus 20% by volume (volume equivalent to 0.5 kg phosphogypsum) of either phosphatic clay (pH 7.4), composted garbage (pH 8.4), sand tailings (pH 6.3) or overburden (pH 4.8). All pots were fertilized weekly with 10 ml of 0.1 M nitrogen. Others also received 0.03 M potassium and/or 0.01 M magnesium. Nitrogen was applied in the form of ammonium nitrate except when potassium or magnesium were added, in which cases some of the N was applied as potassium nitrate or magnesium nitrate. Dolomite mixed into gypsum at 3 g per pot was also used as an alternate source of magnesium. The complete nutrient solution (also 0.1 M N) was prepared from commercially available "Nutrisol". Common bermudagrass seed was planted at the rate of 0.1 mg per pot. After 30 days, the grass was clipped, oven-dried, and weighed. The pH of the phosphogypsum from each pot was determined.

Field Study.

A field experiment was planted on July 25, 1990 on the flat surface at the top of U.S. Agri-Chemicals' phosphogypsum stack located just west of Bartow, Florida. Phosphogypsum had not been added to the stack in more than ten years, and exposure to the weather had increased the pH values of the surface material to near 5.0. The experiment was designed to compare the effects of low amounts of several soil amendments on grass establishment and growth. The treatments included: (1) a non-amended control, (2) one ton per acre of agricultural grade dolomite, (3) two inches of composted garbage, (4) two inches of sand tailings, and (5) two inches of overburden. Individual plots were 12 feet by 24 feet and each treatment was replicated four times. All plots were rototilled to a depth of four inches. The five treatments listed above were broadcast seeded with 25 lb/acre of hulled common bermudagrass, 15 lb/acre of weeping lovegrass, 40 lb/acre of Pensacola bahiagrass, 40 lb/acre of browntop millet *(Brachiaria ramosa)*, and 40 lb/acre of pearl millet *(Pennisetum glaucum)*. All plots were mulched at the rate of 90 50-lb. bales of bahiagrass hay per acre, applied with a hay blower. The hay mulch was crimped-in with a cultipacker roller. The plots were fertilized at the per acre rates of 48 lb. N, 12 lb. P_2O_5, 24 lb. K_2O, 3.5 lb. Mg, 3.7 lb Fe, 1.35 lb. Mn, 0.27 lb Cu, 0.24 Zn, and 0.09 lb. B. Twenty-five percent of the nitrogen was in the slow-release form of isobutyldienediurea (IBDU).

Each plot was harvested with a lawnmower, set at a 2.5 inch cutting height on November 8, 1990. The late harvest date was chosen in order to minimize effects on plant establishment. The plots were fertilized again on April 19, 1991, at the same rate as indicated above, and harvested again on September 19, 1991. Harvested material was ovendried at 60 degrees C and weighed. Additional samples of plant tissue were harvested on September 19, 1991, and analyzed for Ca, Mg, K, P, Zn, Cu, Mn, B, and Fe.

Soil samples were collected from each plot on November 8, 1990. Each sample was a composite of ten cores from a plot. Because the plots were rototilled to a depth of four inches, the samples only included the top four inches. The samples were air-dried and analyzed for pH ($2H_20$:1 "soil") and Mechlich I extractable Mg, K, P, Zn, Cu, and Mn.

The field plots were fertilized on June 5, 1992 at the per acre rates of 50 lb. N, 25 lb. K_20, and 12.5 lb Mg (Twenty-five percent of the N was in the slow-release form of methylene urea). Plant cover was determined on October 6, 1992 by the line-point method, and subplots were harvested by hand clipping.

RESULTS

Greenhouse Study.

Table 1 clearly shows that this sample of weathered phosphogypsum is deficient in both potassium and magnesium. Dolomite was an effective source of magnesium. Phosphatic clay was a good source of both potassium and magnesium, and it may also have enhanced growth through other additional effects on the chemical and physical properties of the phosphogypsum. Neither sand tailings, nor overburden were significant sources of potassium and magnesium when they comprised 20% by volume of the phosphogypsum/"soil" amendment mixture. As we later learned in the field studies, the composted garbage may have been phytotoxic when mixed with phosphogypsum. Phosphatic clay, composted garbage, and dolomite all caused significant increases in pH values. Even the addition of magnesium nitrate (see N+K+Mg vs. N+K treatments; total N levels were the same) caused a slight, but statistically significant, pH increase.

The data indicate that, as a minimum, nitrogen, potassium, and magnesium must be added to weathered phosphogypsum to promote plant growth. The greater growth produced with complete nutrients, N+K+dolomite, or phosphatic clay than with the N+K+Mg treatment suggests that addition of other nutrients or increased pH may be required for optimum growth.

Field Study.

Table 2 shows the plant dry weights, on a per-acre basis, harvested from the soil amendment plots in November 1990, September 1991, and October 1992. Most of the dry matter in 1990 was from the annual cover crops, pearl millet and browntop millet. Because of the late harvest, the annuals were well into senescence, therefore the dry matter values are an underestimate of the actual production. Nevertheless, the data do demonstrate the effects of the soil amendments on plant growth. In 1990 the overburden, dolomite and sand tailing treatments produced significantly more

Table 1. Effect of Fertilizer and Soil Amendments on Growth of Common Bermudagrass in Weathered Phosphogypsum.(1)

Treatment	pH	Plant Dry Weight (g/pot) (1)
N	4.95 ab	0 a
N + K	5.02 ab	0 a
N + K + Mg	5.34 c	510 b
Complete Nutrients	5.26 c	820 c
N + Dolomite	5.85 d	0 a
N + K + Dolomite	6.01 d	840 c
N + Phosphatic Clay (20%)	6.90 e	1460 d
N + Composted Garbage (20%)	7.33 f	0 a
N + Sand Tailings (20%)	5.19 bc	0 a
N + Overburden (20%)	4.81 a	0 a

(1) Means of three replicates. Values followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

Table 2. Effect of Soil Amendments on Plant Growth in the Field on Weathered Phosphogypsum at the U.S. Agri-Chemicals Site.(1)

	Plant Dry Weight (lb/Acre)(1)		
Treatment	Nov. 1990	Sept. 1991	Oct. 1992
Control	430 b	1952 x	3988 m
Dolomite (1 ton/acre)	823 c	2821 y	4260 m
Composted Garbage (2 inches)	64 a	3852 z	4165 m
Sand Tailings (2 inches)	721 c	2761 y	4453 m
Overburden (2 inches)	975 c	2276 xy	3514 m

(1) Means of four replicates. Values followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

growth than the control, while the composted garbage treatment was significantly poorer than the control. Visual comparisons during the growing season and the harvest data suggested that the overburden treatment may have been slightly better than the sand tailing treatments; however, the differences among these treatments were not statistically significant.

In 1991, the perennial grasses had become well-established on the control and the amended plots. In sharp contrast to 1990, the composted garbage amended plot had significantly higher production than the other treatments in 1991. Apparently, the toxic factor(s) had ameliorated throughout the winter, and the accumulated nutrients, from both the unused applied fertilizer and the nutrients originally contained in the compost, contributed to the enhanced growth. Both the dolomite and the sand tailings amendments significantly enhanced grass production above that of the control. Production on the overburden amended plots was not statistically different from the control or the dolomite or sand tailings treatments. In 1992, yield was greater than in 1991, but there were no significant differences among treatments.

Although total grass yield did not differ among treatments in 1992, species composition did (Table 3). Neither weeping lovegrass nor bahiagrass were found on the control or dolomite plots. However, weeping lovegrass was dominant on the composted garbage plots, while percent cover was divided fairly evenly among bermudagrass, weeping lovegrass and bahiagrass on the overburden amended plots. Bermudagrass was clearly dominant on the control, dolomite, and sand tailings amended plots. Bushybeard *(Andropogon glomeratus)* was not planted but naturally invaded the field test plots. Ground covered by plants was between 97 and 100 percent and did not differ significantly among treatments.

By mid-summer, 1991, it was noted that the bermudagrass in the dolomite treated plots appeared greener and more vigorous than in the control plots. The beneficial effect of dolomite could have been due to a pH increase or to a nutritional effect because of the magnesium contained in the dolomite. The symptoms suggested a magnesium deficiency in the control plot, so on August 1, 1991, magnesium sulfate was added to one-half of each of the four control plots at the rate of 12 pounds Mg per acre. Within two weeks the Mg-treated portions of the control plots had become visibly greener. In addition, Table 4 shows that application of additional magnesium sulfate to one-half of each control plot resulted in a much higher concentration of Mg in the plant tissue. These results demonstrate that at the U.S. Agri-Chemicals site, and probably other weathered phosphogypsum sites, magnesium is a key fertilizer element. Initially, only 0.07 lb. of Mg was applied for each lb. of N. In 1991, the control + $MgSO_4$ treatment included 0.32 lb. Mg per lb. N.

The plots amended with sand tailings, overburden, or composted garbage were fertilized at the same rate as the control, but did not exhibit magnesium deficiency symptoms. In addition, concentrations of Mg in plant tissue were slightly (although not statistically) higher with these soil amendments than the control. Thus it appeared that these materials supplied some Mg. Plant tissue Mg was highest with dolomite, which agrees with the effect of dolomite on increasing extractable Mg in phosphogypsum (see Table 5).Unless dolomite or some other Mg-containing soil amendment is added, it appears that somewhat more than 0.07 lb. Mg per lb. N (perhaps 0.2 lb. Mg per lb. N) should be applied to plain phosphogypsum. For these reasons, the Mg rate was increased in 1992 so that 0.25 lb. Mg was applied for each 1.0 lb N. The higher Mg rate applied to all the plots in 1992 may have been responsible for the control treatment having statistically equivalent production to the other treatments that year.

Tissue P was lowest with the composted garbage amendment (Table 4). This could be related to lower solubility due to higher soil pH, or possibly dilution effects because of greater plant growth, or even because of differences in the dominant plant species (weeping lovegrass vs. common bermudagrass). Zn concentrations were several times higher in plant tissue

Table 3. Percent Cover as Affected by Soil Amendments at the U.S. Agri-Chemicals Phosphogypsum Stack in Early October, 1992.[1]

	Control		Dolomite		Composted Garbage		Sand Tailings		Overburden	
Bermudagrass	99.5	a	99.5	a	49.0	b	97.9	a	44.9	b
Weeping Lovegrass	0.0	c	0.0	c	92.2	a	12.0	c	69.3	b
Bahiagrass	0.0	b	0.0	b	10.4	b	1.0	b	54.2	a
Bushybeard	1.0	a	1.6	a	2.1	a	1.6	a	6.8	a
Total Grasses[2]	100.5	c	101.0	c	153.7	b	112.5	c	178.1	a
Ground Cover (Plants)	99.5	a	99.5	a	99.5	a	100.0	a	97.4	a
Litter	0.5	a	0.5	a	0.5	a	0.0	a	2.6	a
Bare Ground	0.0	a	0.0	a	0.0	a	0.0	a	0.0	a

(1) Means of four replicates. Values within rows followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

(2) May exceed 100 percent because of plant overlap.

TABLE 4. Mineral Content of Grass Tissue Harvested September 1991 from the USAC Phosphogypsum Stack as Affected by Various Soil Amendments.[1]

	g/kg				mg/kg				
	Ca	Mg	K	P	Zn	Cu	Mn	Fe	B
Control	6.6a	0.66c	8.0a	3.7ab	19b	4.2b	70bc	44a	1.6b
Control + $MgSO_4$[2]	5.9ab	1.19b	7.8a	4.0a	16b	3.7b	80bc	40a	2.4ab
Dolomite	6.8a	1.62a	7.0a	3.3bc	21b	4.3b	116a	39a	2.6a
Composted Garbage	7.1a	0.78c	7.6a	2.0d	100a	6.0a	114a	43a	2.1ab
Sand Tailings	5.9ab	0.81c	8.5a	3.3bc	26b	4.6b	97ab	45a	1.8b
Overburden	5.4b	0.85c	8.4a	2.9c	25b	4.2b	53c	40a	1.8b

(1) Values are means of four replicates. Values within columns followed by the same letter are not significantly different at the 0.05 level.

(2) Magnesium sulfate, at the rate of 12 lb. Mg/acre, was applied to one half of each of the control plots on August 1, 1991.

TABLE 5. Effect of Soil Amendments on Chemical Properties of Phosphogypsum from the U.S. Agri-Chemicals Site in November 1990.(1)

Treatment	pH	Mehlich I Extractable Elements (mg/kg) Mg	K	P	Zn	Cu	Mn
Control	5.3 b	2.6 a	3.8 a	131 a	0.41 a	0.24 a	0.18 a
Dolomite	5.7 c	33.3 d	3.5 a	87 a	0.40 a	0.20 a	0.17 a
Composted Garbage	6.7 d	8.1 b	7.5 b	132 a	14.15 b	4.69 b	6.10 c
Sand Tailings	5.6 c	10.4 b	4.7 a	1157 c	1.84 a	0.39 a	1.71 b
Overburden	4.9 a	16.2 c	4.6 a	729 b	0.69 a	0.21 a	1.19 b

(1) Means of four replicates. Values within columns followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's Multiple Range Test.

from the composted garbage amended plots, and Cu was also higher with the composted garbage amendment. Tissue Mn was highest when the plots were amended with composted garbage or dolomite. The high tissue Mn with the dolomite treatment is unexpected given the low soil Mn level in the phosphogypsum amended with dolomite (Table 5). Mn was lowest in plant tissue from the overburden amended plots, which had higher extractable soil Mn levels than the dolomite plots. Boron concentrations were similar in magnitude in plant tissue from all the treatments, but the level was significantly higher in tissue from the dolomite treatment than from the control. Soil amendments had no significant effects on plant tissue concentrations of Fe or K. Plant calcium levels were statistically similar in all treatments except the overburden treatment which was significantly less than the control. The plant tissue samples were analyzed for cadmium and nickel, but the concentrations were below the detection limits, so data are not shown here.

Application of one ton dolomitic limestone per acre to the phosphogypsum only increased the pH by 0.4 unit, while Mehlich I extractable magnesium was increased ten-fold (Table 5). These data, coupled with visible greening of portions of the control plots following magnesium sulfate application, suggest that the primary beneficial effect of the dolomite was to increase the supply of magnesium available to the plants. The composted garbage, sand tailings, and overburden also added magnesium to the phosphogypsum, and no visual Mg deficiency symptoms were observed with these treatments in 1991.

The addition of composted garbage increased the pH by 1.4 units and also increased the concentrations of Mg, K, Zn, Cu and Mn. The exact cause of the phytotoxicity observed in 1990 was not determined, but the high levels of Zn, Cu and Mn suggest that metal toxicity might have been involved. The abundant plant growth in 1991 indicates that the phytotoxic factor(s) had diminished. In addition, some of the unused fertilizer nutrients from the previous year were likely available the second year.

The sand tailings increased the pH almost as much as the dolomite. In addition, significant amounts of P, Mg, and Mn were supplied. Although not statistically significant, Zn and Cu levels may have been increased also. The overburden caused a small decrease in pH, while increasing the levels of Mg, P and Mn.

CONCLUSIONS

Excellent stands of bermudagrass can be established directly on weathered phosphogypsum (pH near 5) if adequate amounts of N, K and Mg are supplied. Dolomitic limestone and phosphatic clay are good sources of Mg, while phosphatic clay will also supply K. The other seeded grasses in this study, bahiagrass and weeping lovegrass, were only found when phosphogypsum was amended with overburden, composted garbage or sand tailings. Thus, although plant yield and ground cover were equally good on all treatments by the third growing season, plant species diversity was enhanced by the overburden and composted garbage amendments.

The dolomite, sand tailings and overburden amendments all enhanced plant establishment and growth the first season. The primary reason appears to be the deficiency of Mg in the control and the extra Mg supplied by the amendments. A higher rate of Mg applied in the third growing season appears to have helped eliminate the initial differences among the treatments.

The composted garbage was toxic the first year but enhanced plant growth the second year. The evidence available indicates that a high level of zinc or other metal might have been responsible for the initial phytotoxicity of the composted garbage. Weeping lovegrass was more tolerant to the composted garbage than the other species planted. Interestingly, sewage sludge in a separate study produced similar results to composted garbage when applied alone to phosphogypsum, but application of phosphate clay with the sewage sludge eliminated the toxic effect and promoted plant growth (Richardson 1992). Gonzales et al. (1992) found that the presence of phosphatic clay suppressed cadmium uptake by alfalfa grown in sewage sludge amended sand tailings. Phosphatic clay may have similar effects on plant uptake of other metals as well. Composted garbage at the rate applied to phosphogypsum in this study would not be recommended unless phosphatic clay were also added.

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