INFLUENCE OF TILLAGE AND AMENDMENTS ON VEGETATION ESTABLISHMENT IN PHOSPHOGYPSUM [1]

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__Abstract:__ Chemical and physical characteristics of phosphogypsum (PG) must be ameliorated for successful vegetation establishment. Therefore, a three-year field study was initiated in 1991 to compare the effects of disking vs. rototilling on nutrient content and dry matter yield (DMY) of browntop millet (__Panicum__ __ramosum__) and bermudagrass (__Cynodon__ __dactylon__ [L.] Pers.) grown in PG having a pH of 4.82 and an electrical conductivity (EC) of 2.29 dS/m. The PG was amended with 0, 52, 104, 208, and 416 metric tons/hectare (mt/ha) of phosphatic clay (PC), and 0, 29, 58, 116, and 232 mt/ha of sewage sludge (SS). Fertilizers at 112 kg/ha N, 56 kg/ha K, and 28 kg/ha Mg were selectively added in 1991, but were added to all plots in subsequent years. Tillage influenced pH and DMY in 1991 and 1992, but was not influential in 1993. Tillage did not affect EC in any year. Rototilling resulted in greater DMY in the first two years than did disking. Rates within each amendment affected pH, EC, height, DMY, and tissue nutrient concentrations. Sludge application resulted in much higher Zn concentration in bermudagrass tissue, but levels were not sufficient to cause phytotoxicity. In establishing vegetation on PG, both PC and SS have potential as nutrient sources, but no seed germination was observed in SS-amended plots in 1991 and its detrimental effects need to be investigated further. The data suggest that disking, less energy intensive compared to rototilling, would be more economical in initially alleviating the surface hardness problem on PG to establish vegetation.

Additional Key Words: reclamation, phosphogypsum, phosphatic clay, sewage sludge, disking, rototilling.

__Introduction__

For each metric ton of P_2O_5 produced from phosphate rock, there is co-production of approximately 5 mt of phosphogypsum (PG) as a byproduct. The PG is pumped as a slurry to an impoundment where a dragline is used to move some of the settled PG to raise dike height, resulting in a "pile" or "stack" up to 60 m in height. Currently, stacks in Florida range from 20 ha to 200 ha and occupy over 2,000 ha of land. Chemical processing results in 33 million mt of PG annually (May and Sweeney, 1980), with over 600 million mt already accumulated in stacks. Inherent low-level radioactivity present in PG, mostly from radium-226, has resulted in restrictions on the use of PG (Federal Register, 1992). With this final ruling on PG removal and uses, most PG will remain stockpiled in approximately 20 stacks throughout Florida. When PG stacks cease usefulness as deposition sites, they must be reclaimed in an environmentally acceptable manner.

Establishing a vegetative cover will undoubtedly be part of any reclamation effort. Along with improving aesthetics, vegetative cover should reduce erosion and radon-222 emanation (Richardson, 1994), improve surface runoff quality, and possibly enable use of PG stacks as wildlife habitat. Sparse natural vegetation on PG surfaces indicates that establishment of a vegetative cover is possible. Reasons for sparse vegetation on PG surfaces include residual acidity, nutrient deficiencies or imbalances, low nutrient-holding capacity, and surface hardness.

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Phosphogypsum consists primarily of the moderately soluble neutral salt, calcium-sulfate dihydrate ($CaSO_4.2H_2O$), and will affect electrical conductivity (EC), but should have minimal effect on soil acidity. However, residual phosphoric and sulfuric acids from the acidulation process, and secondary reaction products such as hydrofluoric and hydrofluorosilicic acids, can render PG highly acidic. Acidity of PG stacks in Florida commonly range from pH 2.1 to pH 3.8 (May and Sweeney, 1980). However, Ho and Zimpfer (1985) reported PG pH to be as high as 6.0 on older, inactive PG stacks. Studies by Lundberg et al. (1977) and Sartain (1985) have shown bermudagrass to tolerate high acidity. Therefore, bermudagrass (Cynodon dactylon [L.] Pers.) establishment and growth on PG may be possible.

Phosphatic clay (PC), a byproduct washed from the phosphate ore during the beneficiation process, has a neutral to slightly alkaline pH and may be used as a possible PG amendment for reducing acidity and as a plant-nutrient source (Mislevy et al., 1989). Sewage sludge (SS) also generally has a near-neutral pH and, therefore, should increase PG pH upon application. Sewage sludge is a source of nutrients (Sommers, 1977) and has gained widespread use in reclamation projects (Sopper, 1993).

The objective of this study was to compare disking with rototilling and evaluate SS and PC as amendments to PG by measuring pH and EC of PG, and dry matter yield (DMY) plus nutrient concentrations in browntop millet (Panicum ramosum) and bermudagrass grown on a PG stack.

Materials and Methods

This field study was conducted on the regraded top of the Estech Inc., PG stack that has been inactive for over 20 yrs. Consolidated PC was obtained from the surface of a PC settling pond adjacent to the Mined Lands Agricultural Research/Demonstration Project (MLAR/DP) site in Bartow, FL. Anaerobically digested SS was collected from an advanced wastewater treatment plant (AWTP), near the City of Tampa, FL.

Experimental plots were 1.2 meter (m) by 2.2 m. Clay was applied at rates of 0, 52, 104, 208, and 416 mt dry weight/ha, whereas SS was applied at 0, 29, 58, 116, and 232 mt dry weight/ha. In 1991, control plots were supplemented with 112 kg N/ha as ammonium nitrate, 56 kg K_2O/ha, and 28 kg Mg/ha, as potassium-magnesium sulfate whereas PC-amended plots received 112 kg/ha N alone, and no fertilizer was added to SS amended plots. All plots, regardless of amendment, were fertilized with 112 kg N/ha, 56 kg K_2O/ha, and 28 kg Mg/ha in subsequent years.

Upon amendment and fertilizer application in mid July, 1991, plots were disked or rototilled to a depth of approximately 10 cm. Browntop millet was broadcast seeded at 26 kg/ha and bermudagrass was broadcast seeded at 58 kg/ha. Grasses were harvested in late August within a 2 m^2 area from each plot. Irrigation was not used in this study. The harvested plants were oven-dried at 70°C. In 1991, browntop millet was dominant in the harvest, but tissue nutrient analysis was performed on the entire mixed harvest. In subsequent years, nutrient analyses were performed only on bermudagrass because the browntop millet, an annual grass, had disappeared. In 1992, fertilizers were applied in early July and plants were harvested in early September, whereas in 1993 fertilizers were applied in late July and grasses were harvested in late October.

Plot PG samples were analyzed for pH and EC in a 2:1 (water:PG) ratio slurry with a 4 h standing time before measurements were taken. For elemental analyses, PG samples were extracted using Mehlich-I extractant according to Hanlon and DeVore (1989). Saturation extract EC (EC_e) estimates from EC values were obtained using the following equation:

$$EC_e = [(EC - 2.20) * 7.69] + 2.20,$$

where the constant 7.69 was obtained by taking the ratio of water content at EC measurement to that of the material at optimum moisture content (approximate field capacity), which for this study was estimated to be

26% by weight. The constant 2.20 was the EC of water saturated with pure $CaSO_4.2H_2O$ at 25°C. Due to the high pH of PC, it was extracted with Mehlich-3 extractant using a procedure similar to that for the Mehlich-I extraction. Elemental analysis was accomplished using inductively coupled argon plasma spectrometry. Sewage sludge samples were dry-ashed and analyzed for total elemental concentrations. Analytical results for various elements in PG, PC, and SS are shown in Table 1, along with Kjeldahl-N content in SS, which was determined using an autoanalyzer.

Experimental plots were arranged in a split-plot design such that amendments and tillage were crossed, with rates nested within amendments. Each amendment was replicated four times. Variance sources were tested by analysis of variance (ANOVA) at the 0.05 level of probability. Regression analyses were used to test for polynomial effects of actual amendment rates (excluding control). Single-degree-of-freedom contrasts were used for mean separations.

Results and Discussion

Phosphogypsum and Amendment Analyses

Initial Mehlich-I extractable nutrient analyses (Table 1) indicated that the PG was inadequate in K and Mg concentrations for optimum plant growth. Richardson (1993) also reported PG to be low in K and Mg. The PG from this stack was lower in extractable nutrients compared to PG from active stacks (Patel et al., 1994). The low nutrients may be attributed to the stack having been inactive and subject to weathering and leaching for over 20 yr. This hypothesis was supported by finding a pH of 4.82 and an EC of 2.29 dS/m in PG at this stack compared to a pH of 2.78 and an EC of 4.16 dS/m for PG from an active stack (Patel et al., 1994).

Clay and SS analyses indicate their potential as sources of nutrients, particularly K and Mg. Bromwell and Carrier, Inc. (1989) reported PC to be valuable as a nutrient source in the production of high value cash crops. Mislevy and Blue (1981) and Mislevy et al. (1989) also reported higher yields due to nutrients and improved water holding capacity in sand tailings resulting from PC addition. The high N content (5.9%) of SS should be of additional benefit to the plants as a nutrient source.

Acidity and Electrical Conductivity of Amended Phosphogypsum

In each of the three years, tillage influenced pH differently, affecting pH in the first two years, but not in 1993. Also, in all three years, PC and SS caused increases in pH. In 1991, PC rates produced linear pH responses for both tillage methods [Disk: pH = 5.10 + 0.00300(PC), r^2 = 0.81, C.V. = 4; Rototill: pH = 5.24 0.00287(PC), r^2 = 0.81, C.V. = 4], whereas the SS rates produced quadratic pH responses [Disk: pH = 5.23 + 0.0122(SS) - 3.24E-5$(SS)^2$, R^2 = 0.66, C.V. = 4; Rototill: pH = 5.09 + 0.133(SS) - 3.81E-5$(SS)^2$, R^2 = 0.68, C.V. = 4]. Regression analyses indicated a maximum pH of 6.37 with 188 mt SS/ha when disking, whereas maximum pH with rototilling would be 6.25 with 175 mt SS/ha application. In 1992, disking produced quadratic pH responses with both amendments [pH = 4.54 + 0.00787(PC) - 1.06E-5$(PC)^2$, R^2 = 0.85, C.V. = 4; pH = 4.79 + 0.00536(SS) - 1.27E-5$(SS)^2$, R^2 = 0.77, C.V. = 2]. Regression indicated that the maximum pH of 6.00 would be attained at 372 mt/ha PC application and pH 5.35 with 210 mt/ha SS. Rototilling produced linear pH responses with both amendments [pH = 5.04 + 0.00197(PC), r^2 = 0.80, C.V. = 3; pH = 4.93 + 0.00260(SS), r^2 = 0.72, C.V. = 3]. Eventhough tillage did not affect pH in 1993, rates within each amendment produced a linear pH increase [pH = 4.83 + 0.00259(PC), r^2 = 0.79, C.V. = 4; pH = 4.86 + 0.00280(SS), r^2 = 0.65, C.V. = 3]. Findings by Patel et al. (1994) and Richardson (1994), indicate that the pH of 4.82 for the PG in this study is suitable for bermudagrass germination and growth.

Table 1. Concentration of selected elements in phosphogypsum, phosphatic clay and sewage sludge used in the study[1]

Element	PG Mehlich-I extractable	Phosphatic clay Mehlich-III extractable	Sewage sludge Total conc. Dry ashing
		mg/kg	
N	ND	ND	59,000
P	106	74	14,237
K	1	245	807
Ca	4,234	ND	ND
Mg	3	1,967	2,114
Zn	0.4	3	902
Cu	0.3	2	428
Mn	0.1	5	67
Fe	5	100	11,605
Al	42	250	4,904
B	ND	ND	34
Cd	ND	ND	16
Pb	ND	ND	154
Ni	ND	ND	41

[1] Mean of five replicates.
ND: Not determined.

Although, tillage did not influence EC, rates within amendment influenced EC in all three years, suggesting that half as much SS resulted in salinity levels equivalent to that of PC. In 1991, rates within PC produced a linear EC response ($EC = 2.21 + 0.00133(PC)$, $r^2 = 0.74$, C.V. = 4), however, no trend was observed for SS rates. Although rates affected EC in 1992, no significant trend was apparent for either amendment. In 1993, only PC rates resulted in linear EC increase [$EC = 2.18 + 0.000597(PC)$, $r^2 = 0.68$, C.V. = 3]. Data also suggest that rates of amendments influenced EC greater in 1991 than in subsequent years. For PC-amended PG, the EC (including control) averaged 2.43, 2.29, and 2.28 dS/m, and for SS-amended PG averaged 2.50, 2.27, and 2.33 dS/m in consequent years. The EC samples for 1991 were taken six weeks after amendment application, and therefore, it is likely that the salinity inherent to the amendments influenced EC measurements. The salinity threshold for bermudagrass growth reduction is 6.9 dS/m (EC_e), above which a yield decrease is expected (Hanlon et al., 1993). For PG in this study, EC_e values ranged from 2.28 to 6.66 dS/m, indicating that salinity should not affect bermudagrass yield.

Influence of Amendments on Browntop Millet Height

In 1991, browntop millet height was measured for only the PC amended plots as no germination occurred in plots amended with SS. Richardson (1993) observed a similar inhibitory effect when PG was amended with composted municipal waste (garbage). At harvest (late August), tillage influenced height responses to PC amendment rates. For both tillage methods, a quadratic increase in height was produced by PC rates ($Height = 37 + 0.15(PC) - 1.5E\text{-}4(PC)^2$, $R^2 = 0.92$, C.V. = 6; and $Height = 42 + 0.15(PC) - 1.7E\text{-}4(PC)^2$, $R^2 = 0.96$, C.V. = 4, respectively). Extrapolation indicated that maximum height with disking would have been 74 cm at 487 mt/ha PC, whereas for rototilling, maximum height of 75 cm would have occurred with 439 mt/ha application. Regardless of tillage, height increases were observed with each increase in PC rate. Bermudagrass height was not measured for any year.

Influence of Amendments on Dry Matter Yield

In 1991, DMY (dominantly browntop millet) was affected by tillage and PC rates. Random sampling revealed that bermudagrass comprised less than 5% of the total DMY from PC amended plots, with disked plots containing a higher percentage of bermudagrass than rototilled plots. Regardless of tillage, bermudagrass in the harvest decreased with increasing PC rates. This observation suggests a canopy effect by the erect growing browntop millet which also increased with both increasing PC rates and rototilling. The DMY of the decumbent growing bermudagrass, can therefore, be expected to be reduced due to greater solar-radiation interception by the millet. Average yield from PC amended plots (excluding control) was 2,224 kg/ha with disking and 2,665 kg/ha with rototilling. A quadratic increase in DMY (Table 2) was produced by PC rates [$DMY = 384 + 17.4(PC) - 0.0231(PC)^2$, $R^2 = 0.88$, C.V. = 15] indicating a maximum DMY of 3,661 kg/ha at 376 mt PC/ha.

In 1992, tillage and rates within amendments affected DMY. Bermudagrass DMY from disked plots (excluding control) was 4,966 kg/ha and from rototilled plots was 5,485 kg/ha. Yield did not indicate any trend with increasing PC rates, whereas a slight, but significant linear DMY (Table 3) response to increasing SS rates [$DMY = 4205 + 10(SS)$, $r^2 = 0.47$, C.V. = 16] was indicated.

Table 2. Browntop millet DMY for PC amended PG in 1991[1]

PC	DMY
---mt/ha---	---kg/ha---
0	360a[2]
52	1,153b
104	2,065c
208	2,935d
416	3,623e

[1] Mean of eight replications.
[2] Means within the same column followed by different letter are significantly different at 0.05 level of probability.

Table 3. Bermudagrass DMY for PC and SS amended PG in 1992[1]

PC	DMY	SS	DMY
mt/ha	kg/ha	mt/ha	kg/ha
0	4,583a[2]	0	4,583a[2]
52	5,114a	29	3,980a
104	5,247a	58	5,232a
208	5,228a	116	5,607b
416	5,027a	232	6,369b

[1] Mean of eight replications.
[2] Means within the same column followed by different letter are significantly different from the control at 0.05 level of probability.

In 1993, no tillage effect was observed, however, differences for rates within amendments were still evident on total DMY. Total DMY from PC amended plots was 2,809 kg/ha, and that from SS amended plots was 3,410 kg/ha. No weed management was conducted in 1993, therefore, total DMY included dog fennel (Eupatorium capillifolium) and bushy beardgrass (Andropogon glomeratus). Analyses on only bermudagrass DMY (excluding the two weed species), similarly indicated no tillage effect, but showed rates within amendments to affect DMY. Both total and bermudagrass DMY showed (Table 4) slight, but significant positive linear responses to SS rates [Total: DMY = 2299 + 10(SS), $r^2 = 0.45$, C.V. = 27; Bermudagrass only: DMY = 1141 +12(SS), $r^2 = 0.47$, C.V. = 38]. No trends were observed for DMY from PC amended plots. Yield of bermudagrass in 1993 were half of those observed in 1992. Competition for nutrients, water, as well as sunlight, may have influenced bermudagrass DMY in the third year. Both dog fennel and bushy beardgrass have erect growth patterns as compared to the decumbent growth pattern of bermudagrass resulting in possible competition for solar radiation, and therefore, less overall DMY. At another PG stack, Patel (Unpublished) observed bermudagrass growth to diminish considerably in a single year when dog fennel and bushy beardgrass were not managed.

Table 4. Total DMY and bermudagrass DMY for PC and SS amended PG in 1993[1]

PC	Total[2] DMY	Bermuda DMY	SS	Total[2] DMY	Bermuda DMY
mt/ha	kg/ha	kg/ha	mt/ha	kg/ha	kg/ha
0	2,198a[3]	1,547a[3]	0	2,198a[3]	1,547a[3]
52	2,627a	1,813a	29	2,633a	1,899a
104	2,612a	1,929a	58	2,836a	2,003a
208	2,927a	1,792a	116	3,505b	2,794b
416	3,068b	1,775a	232	4,670b	4,306b

[1] Mean of eight replications.
[2] Comprises of bermudagrass, dog fennel and bushy beardgrass.
[3] Means within the same column followed by different letter are significantly different from the control at 0.05 level of probability.

Browntop Millet and Bermudagrass Nutrient Concentrations

Concentrations of nutrients in browntop millet were not influenced by tillage methods, but were affected by PC rates. Concentrations of nutrients were compared to those compiled by Jones (1980) for several species, due to a lack of such information on browntop millet (Table 5). Nutrient levels were generally adequate. However, K at the two lower PC rates, Cu at the highest rate, and Mn for the control and highest rate were marginal. Clay addition affected tissue concentrations of all nutrients except Fe. Magnesium and Mn levels increased with PC application, whereas all others decreased.Additionally, Mn concentration decreased with increasing PC rates. It is likely that PC has a tendency to adsorb certain cations rendering them less available for plant uptake or that the increase in pH with addition of PC resulted in precipitation thereby reducing availability to plants. It is also likely, that the decrease in P with increased PC may be attributed to the precipitation of P with Ca as pH rises, since PG is saturated with Ca, thus reducing P availability.

In 1992 and 1993, bermudagrass nutrient concentrations were also not affected by tillage, but were influenced by PC and SS rates. Nutrient concentrations for both years were similar, except for Cu which was almost four-fold lower with PC application and almost three-fold lower with SS in 1993 than in 1992

Table 5. Tissue nutrient concentrations for browntop millet grown on PC amended plots in 1991[1]

Application	Mg	K	P	Zn	Cu	Mn	Fe
--mt/ha--	g/kg			mg/kg			
0	3.9	13.7	8.9	32	9	16	109
52	7.8	7.4	7.3	26	6	43	111
104	9.0	7.8	6.2	23	5	32	112
208	9.2	10.3	5.7	24	4	26	97
416	7.3	16.2	4.7	22	3	15	90

[1] Mean of four replicates.

and therefore, only the 1993 data are shown (Table 6). According to Jones' (1980) nutrient sufficiency ranges, most nutrients were adequate for the control and all rates of both amendments, except Mg, which was low regardless of amendment or year. Micronutrient concentrations were generally higher with sludge application, but were not sufficient to cause phytotoxicity. The Zn concentrations were high, but Sartain (1992) reported bermudagrass growth to be unaffected despite tissue concentrations ranging from 124 to 355 mg Zn/kg. Similarly, King and Morris (1972) reported no yield reduction with bermudagrass tissue Zn concentration of 340 mg/kg.

Table 6. Tissue nutrient concentrations for bermudagrass grown on PC and SS amended plots in 1993[1]

Rate	Mg	K	P	Zn	Cu	Mn	Fe
--mt/ha--	g/kg			mg/kg			
PC							
0	0.8	8.5	2.1	23	2.8	19	41
52	1.1	8.1	2.0	22	2.5	28	42
104	1.2	7.9	2.0	24	2.8	26	41
208	1.1	8.0	2.1	25	2.8	27	41
416	1.4	8.0	2.0	23	2.9	24	44
SS							
0	0.8	8.5	2.1	23	2.8	19	41
29	0.9	8.4	2.3	39	3.9	21	43
58	0.8	8.8	2.6	56	4.6	21	43
116	0.9	8.4	2.8	96	5.4	30	50
232	1.3	9.3	2.7	129	5.9	47	52

[1] Mean of eight observations.

Summary and Conclusions

The pH and EC of PG in this study generally did not affect bermudagrass germination and growth. It was also evident that the influence of weather, particularly leaching can greatly affect not only the pH and EC, but also nutrient availability, especially K and Mg. Tillage increased pH initially, but had no effect on EC and tissue nutrient concentrations. However, the more intense tillage from rototilling resulted in greater height and DMY of browntop millet than did disking in the first year, but as with pH, bermudagrass DMY was not affected by tillage in the third year. Management practices to control undesired plant species must be considered if a bermudagrass stand is to be sustained. Even though cost analysis on the use of either disk or rototilling was not conducted, disking is less energy intensive and therefore, more cost effective for establishing vegetation on PG. The PC and SS sources would both be beneficial in supplying nutrients. However, seed germination and growth were initially hindered by SS in the first year, but the detrimental effect disappeared by the second year and SS resulted in higher DMY than PC in subsequent years. Increasing SS rates did result in increased tissue concentrations of micronutrients, particularly Zn, but the levels were not sufficient to cause phytotoxicity. Further studies investigating the initial lack of seed germination and plant growth with SS are in progress.

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