Evaluation of FGD-Gypsum to Improve Forage Production and Reduce Phosphorus Losses from Piedmont Soils

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ABSTRACT

Flue gas desulfurization gypsum (FGD-gypsum), a byproduct from coal fired electricity generators, has the potential for beneficial use in agricultural systems as a soil amendment. Similar to mined gypsum it can improve soil chemical and physical properties and increase crop productivity. Use of FGD-gypsum may also provide environmental benefits by helping to decrease the solubility of phosphorus and lower the adverse effects of P runoff on off-site water quality. We measured the effects of FGD-gypsum on runoff, P and heavy metal transport, and movement of fecal indicator organisms on a Cecil soil using rainfall simulation. The study was conducted on a Coastal bermudagrass hay field at the USDA-ARS, J. Phil Campbell, Sr., Natural Resource Conservation Center near Watkinsville, GA. Runoff amounts were not significantly different with increasing rates of FGD-gypsum when tested at 3 months after application. Levels of P in runoff from plots treated with 6 tons/ac of poultry litter decreased with the addition of FGD-gypsum. Similar decreases were seen for potassium, copper, and arsenic. Most heavy metals were below the detection limits for our analysis methods. Limited rainfall during the first forage growing season limited production and there was no indication of the effects of the FGD-gypsum treatments. Our preliminary results indicate that FGD-gypsum can help reduce P and other heavy metal losses on areas receiving poultry litter in the Southern Piedmont

INTRODUCTION

Flue gas desulfurization gypsum (calcium sulfate dihydrate, $CaSO_4 \bullet 2H_2O$) is produced as a byproduct of forced oxidation wet scrubbers used to reduce sulfur emissions from coal fired power plants. About 16.1 million metric tons (mega grams, Mg) of FGD gypsum were produced in the United States in 2008[1]. About 60 percent was beneficially reused most commonly in gypsum panel products such as wallboard. Agriculture reuse is only about 253,000 Mg (3 %) while approximately 847,000 Mg of mined gypsum is used annually[2]. Greater quantities of FGD gypsum are expected to become available as more forced oxidation wet scrubbers are installed in response to federal and state clean air initiatives. Because FGD gypsum is comparable to mined gypsum there is a significant potential for greater application and use in agricultural settings.

Gypsum use in agriculture provides plant nutrients, improves soil physical and chemical properties, and increases crop productivity[3]. The Ca and S in gypsum are readily utilized as nutrients by plants. Gypsum also improves soil aggregation which in turn increases water infiltration and reduces runoff on highly erosive soils. Research has shown that addition of gypsum to highly eroded soils of the southeastern USA and other regions can improve crop rooting[4]. The increase in rooting is due to reduction of the negative effects of soluble aluminum which increases as soil pH declines below 5.2. Both the Ca and SO_4 in gypsum help reduce the solubility of the Al, and therefore increase plant rooting depth for improved water and nutrient uptake as a direct effect and crop productivity indirectly. In addition, Ca from gypsum can reduce solubility of phosphorus (P)[3]. Loss of soil P in runoff is a problem in areas where poultry litter (PL) and other animal wastes have been applied in excessive amounts to agricultural land. Calcium reacts with P in the soil to form a compound with limited solubility and that reduces the potential for P losses in runoff and any negative impacts on off-site water quality.

Because FGD Gypsum has not been used as a soil amendment on a large scale, and because of concerns about potential contaminant contents (such as Hg, As, and other heavy metals), the US Department of Agriculture, Agricultural Research Service and the US EPA Office of Office of Resource Conservation and Recovery are collaborating on studies at Watkinsville, Georgia and Auburn, Alabama to establish the agricultural value of FGD gypsum as a soil amendment and determine safe levels of FGD gypsum application. This paper presents preliminary results from research being conducted at the J. Phil Campbell, Sr., Natural Resource Conservation Center in Watkinsville, GA by USDA scientists. The research center is located in the Southern Piedmont physiographic region which lies along the eastern face of the Appalachian Mountains and covers 16.7 million hectares from Alabama to Virginia. Most of the soils of the region are highly eroded due to the rolling terrain, intensive rainfall and the long period of agricultural use. Acid subsoil, low aggregate stability, poor infiltration and excessive runoff and high levels of soil P are common for soils of the region.

MATERIALS AND METHODS

We measured the effects of FGD-gypsum on runoff, P and heavy metal transport, and movement of fecal indicator organisms on a Cecil soil using rain fall simulation in the spring of 2009. The research plots were established on a bermudagrass field which was over seeded with rye in the fall of 2008. In April 2009 the rye was harvested and individual plots flagged. Six treatments were chosen for the study. Four rates of FGD gypsum (0, 2.2, 4.5, 9.0 Mg $ha^{-1} \approx 0, 1, 2, 4$ ton $acre^{-1}$) applied with poultry litter (13.4 Mg ha $\approx$ 6 ton/acre) and two control treatments: one without FGD gypsum and PL and the other only with 4 tons FGD gypsum. The six treatments (gypsum-litter: 0-0, 0-13.4, 2.2-13.4, 4.5-13.4, 9.0-13.4, & 9-0) are replicated three times making 18 plots. The experimental design is a randomized block with three replications.

Runoff plots [1 m by 2 m (3 ft by 6 ft)] were located in the center of larger plots [4 m by 6 m (13 ft by 20 ft)] to provide a border with similar gypsum and poultry litter treatment. Metal plates were driven into the ground with ~5 cm extending above the soil surface to eliminate run-on to the rainfall plot area. A runoff collecting metal plate-flume combination was placed at the down slope position of the plots. The rainfall simulator was designed to deliver 85 mm of water per hour from a single (type of nozel). The rainfall rate of 85 mm h^{-1} represents an approximate 1-in-50-yr return period for a 1-h rainfall in the area. The total amount of rain applied to each plot was variable because we considered the runoff event to begin when we measured runoff and not when we began to apply water to the plots. The water applied for the rainfall simulations originated from the Oconee County residential water supply system and was processed (further cleaned up?) through a deionization system prior to application to the plots.

Rainfall simulations were conducted on June 6-12, 2009 immediately after the first harvest of bermudagrass. This is approximately 3 months after treatment applications. We collected soil samples (0 to 15 cm) before and after the rainfall simulation and runoff samples at 10 minute intervals during the rain simulation (for one hour after runoff began) in clean 1-L polypropylene bottles. We also collected the total amount of runoff during the hour of runoff for a composite sample in a 190 L PVC container. Soil samples were analyzed for nutrients and microorganisms. Water samples from the June 22, 2009 rainfall simulation study were analyzed for soluble P, K, S Al, B, Ca, Cu, Fe, Mg, Mn, Na, and Zn using ICAP. Total nutrients and environmental metals were also determined (N, P, Al, Sb, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Ni, K, Ag, Na, V, Zn, As, Hg, Se, and Tl). All analytical methods conformed to EPA standard methods. In addition water samples were analyzed for fecal indicator microorganisms and sediment content.

RESULTS

Total runoff and the ratio of runoff to rain applied are given in Figures 1 and 2.

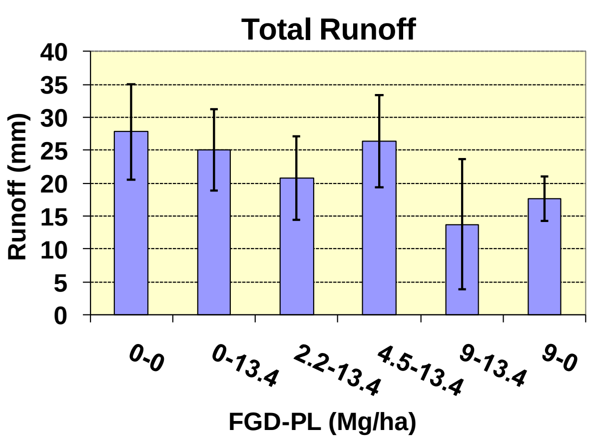

Figure 1. Total runoff.

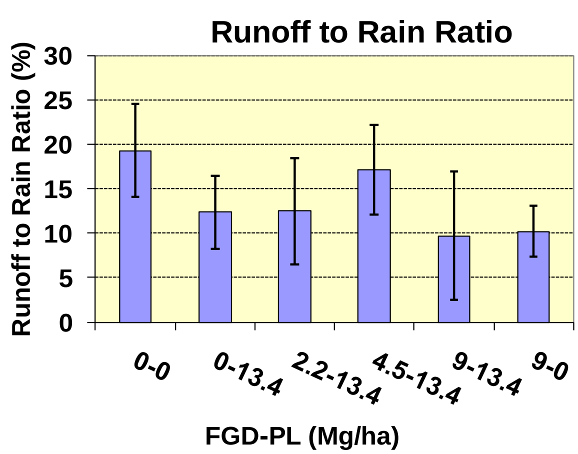

Figure 2. Runoff to rainfall ratio.

Neither runoff nor the runoff-to-rainfall ratio was influenced by the FGD gypsum or the PL treatments. There was a large amount of variability from plot to plot which may have been related to the very dry conditions prior to and during the time we ran the rainfall simulations. This variation may have prevented the detection of a FGD gypsum effect.

The graphs below are for nutrients or metals detectable in the composite sample and where significant treatment effects were determined by analysis of variance. As would be expected Ca increased with increasing rates of FGD-gypsum but there was no influence from the poultry litter (Figure 3). Levels of K and Mg were influenced by PL but not by FGD gypsum (Figure 4). Phosphorus concentrations in the runoff were influenced by PL, FGD gypsum and the interaction between the two (Figure 4). The interaction was the result of the differential impact of poultry litter on P with increasing FGD gypsum. This is consistent with data from the Auburn site. The reduction in P was significant even at the 1 ton/acre rate. Concentrations of Cu, Mn, and As are shown in Figure 5. The PL influenced the amount of Cu and As observed (note that the As values were multiplied by 10 so that treatment differences could be shown on the graph). Concentrations of Mn increased with increasing rates of FGD gypsum. The poultry litter was a source of Cu, As, and Mn (Table 1).

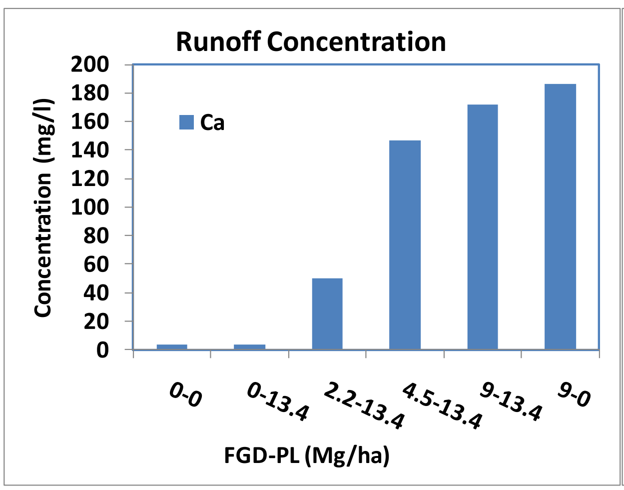

Figure 3. Calcium concentration (mg/L) in the composite runoff sample.

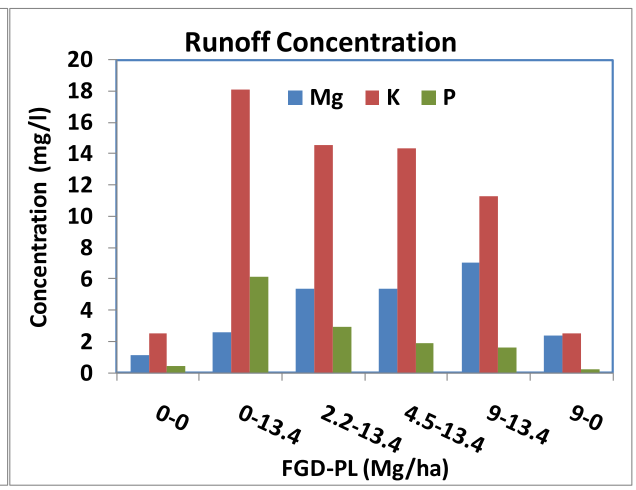

Figure 4 Concentrations (mg/L) of Mg, K, and P in the composite runoff sample.

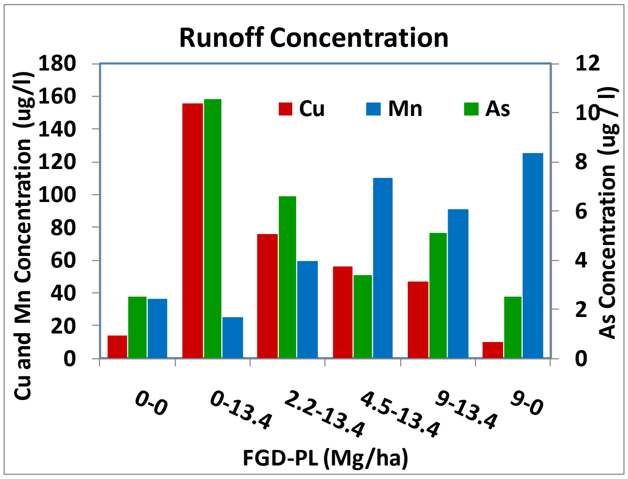

Figure 5 Concentrations (ug/L) of Cu, Mn, and As in the composite runoff sample.

The runoff samples were also analyzed for additional nutrients and metals to determine the potential contribution to runoff from the application of FGD gypsum. The water samples were analyzed for both total concentration and dissolved components of elements. Table 1 provides the list of elements that were measured, but were not detected at the detection limits of the methods used.

Table 1. Non-detected elements in the runoff from the rainfall simulations.

Total elements:		Dissolved elements	
Antimony	Mercury	Antimony	Mercury
Barium	Nickel	Arsenic	Nickel
Beryllium	Silver	Barium	Silver
Cadmium	Vanadium	Beryllium	Vanadium
Chromium	Selenium	Cadmium	Selenium
Cobalt	Thallium	Chromium	Thallium
Lead	Hexavalent Cr	Cobalt	Hexavalent Cr
		Lead	

Since mercury levels in FGD gypsum is of particular concern, special attention was paid to detection of mercury in the runoff samples. All of the runoff samples were determined to be lower than the detection limit ≈ <0.5 µg/L (parts per billion). No mercury was detected in any of the composite runoff samples for any of the treatments. This indicated that while detectable levels of mercury were in the FGD gypsum, there was little or no movement in the runoff water and should not pose a risk from application to pastures in Piedmont soils.

CONCLUSIONS

Our results from the one time application of FGD gypsum indicate positive reduction in P levels in runoff. FGD gypsum should therefore be useful for reducing risk of P loss and improving water quality in runoff from areas where poultry litter is used as a nutrient source. The data also indicates limited or no losses of elements of environmental concern from the FDG gypsum. At this point FGD gypsum appears to have significant potential for beneficial uses in agricultural systems. Additional rainfall simulations will be completed after three years of application which will add to our environmental assessment of FGD gypsum.

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