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Erosion Control by Amending Soil with Synthetic Gypsum

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ABSTRACT

Gypsiferous material is a byproduct of scrubbing flue gases for SO_2 reduction from coal burning. It is formed by precipitating gaseous SO_2, and results in improved air quality emissions. One method of scrubbing stack gases is called wet flue gas desulfurization (FGD). A study was conducted to explore the benefits of using FGD as a soil amendment. In Sullivan County, IN, a local farmer broadcast FGD in the form of synthetic gypsum in strips to several fields and rainfall simulator plots were setup to study gypsum's effect on erosion. A constant rainfall rate of 56 mm h^{-1} was applied and runoff samples were collected. Infiltration rate, soil loss, and surface sealing were analyzed to determine the effects of gypsum. Surface sealing played a major role in the reduction of water intake. Gypsum increased electrolyte concentration of water at the surface of the soil causing clay flocculation thus reducing sealing. Dispersion of clays at the surface can clog surface pores and promote sealing which reduce the ability of water to infiltrate. Increasing the quantity of water into the soil is controlled by surface hydraulics, and when the infiltration rate is increased, runoff and soil loss rates are reduced. This research benefits both the electric power industry and agriculture by finding practical and beneficial uses for byproducts that were formerly waste materials.

INTRODUCTION

Upon the enactment of the Clean Air Act (CCA) of 1970, and the 1990 amendments of the CAA, even existing coal fired power plants needed to improve the quality of their air emissions. Title IV of the CAA primary goal was to reduce the annual SO_2 emissions. Electric utility plants are responsible for 69.4% of SO_2 emissions (EIA, 1997). In compliance with the environmental law, Indianapolis Power and Light Inc. (IPL) installed a system that removes over 90% of the SO_2 from flue gas before it leaves the smokestacks (IPL, 1995). This procedure involves wet limestone scrubbers on coal fired boilers and results in a material referred to in publications as FGD (flue gas desulfurization). Limestone is finely pulverized and mixed with water to form a slurry. As flue gas from the boiler reaches the scrubber system, it is sprayed with the slurry. The SO_2 in the gas reacts with the slurry to form a gypsiferous material primarily $CaSO_3 \bullet XH_2O$. This method for removing sulfur greatly reduces air emissions and with secondary oxidation creates synthetic gypsum ($CaSO_4 \bullet 2H_2O$) formerly used in the wallboard industry or landfill. The utilization of this byproduct in agriculture is of economic interests for all because it provides another outlet for the use of the byproduct.

Many studies have been conducted using gypsum like by-products from coal companies such as fly ashes, bottom ash, cyclone slag and fluidized bed combustion and wet and dry flue gas desulfurization (Norton, 1995; Reichert, 1996; Zaifnejad et al., 1996; Alva, 1991; Stout and Priddy, 1996). Most of these studies were conducted on soils with saline, sodic, or subsurface acidic properties. The objective of this study was to determine if IPL synthetic gypsum provides beneficial effects for controlling soil erosion and water infiltration.

MATERIALS AND METHODS

For the field and plot scale research, sites with Iva, Ava, and Cincinnati silt loam series were used (Aeric Hapludalfs, Aquic Hapludalfs, and Typic Hapludalfs, respectively). (Table 1). The design of the project involved comparing the gypsum treatments with the control areas in the same field. We conducted these experiments on a corn/soybean rotation in no-till fields. The fields were prepared in the spring with the gypsum surface applied using a broadcast spreader, and applied at rate of 2.2 Mg ha^{-1} in strips (Fig. 1).

The FGD material comes from the clean coal technology used at the Petersburg IPL Power Plant (Table 2). The synthetic gypsum produced from this process is greater than 95% pure calcium sulfate dihydrate ($CaSO_4 \bullet 2H_2O$) (IPL, 1995). By-product gypsum is below the permit levels of heavy metals as determined by the Resource Conservation and Recovery Act, (Table 2) and permitted by the Indiana Department of Environmental Management for land application in Indiana.

We conducted plot studies on a field during the corn year of the corn/soybean rotation. The plot scale methods included studying the effects of tilled soils versus no-till soils in gypsum treated areas as opposed to the control areas. The plots used in the experiment were 6m long by 1m wide with sheet metal providing the boundaries on a 5% slope. We used a ladder type rainfall simulator with the nozzles 2.75 meters above the ground, and a computer controlled program that enabled it to rain at a constant target rate of 56 mm hr^{-1}. De-ionized water of similar quality as natural rain was used. During the experiment, runoff was collected at the plot end until a steady state was reached. Discharge and sediment concentrations were measured gravimetrically

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Table1. Field and scale plot study soils: Physical and chemical properties of dominant soils in the study.

Soil Series	Depth	Silt	Clay	Sand	pH	K	Mg	Ca	S
		Particle Size Analysis			Soil Chemical Properties				
	cm	%	%	%		mg kg^{-1}			
Iva	0-23	79.76	11.44	8.80	6.9	86	70	1277	43
	23-53	55.70	40.20	4.10	6.4	117	175	1660	94
	53-66	68.40	16.60	15.00	4.5	114	394	1131	96
	66-102	78.36	14.64	7.00	4.8	115	620	1055	94
	102+	79.16	13.24	7.60	5.8	103	700	1123	34
Ava	0-23	73.58	13.92	12.50	6.1	140	235	1194	10
	23-43	76.98	16.92	6.10	4.6	125	385	1121	75
	43-61	74.34	19.76	5.90	4.6	102	441	964	64
	61-86	75.38	17.12	7.50	4.5	90	508	849	47
	86+	66.88	16.52	16.60	5.1	88	589	901	34
Cincinnati	0-20	82.56	12.64	4.80	5.7	109	119	1150	77
	20-38	83.22	14.68	2.10	4.7	105	199	1136	94
	38-66	79.42	18.48	2.10	4.3	107	410	869	97
	66-106	80.62	16.48	2.90	4.5	84	521	644	31
	106+	71.82	14.48	13.70	5.3	68	618	746	14

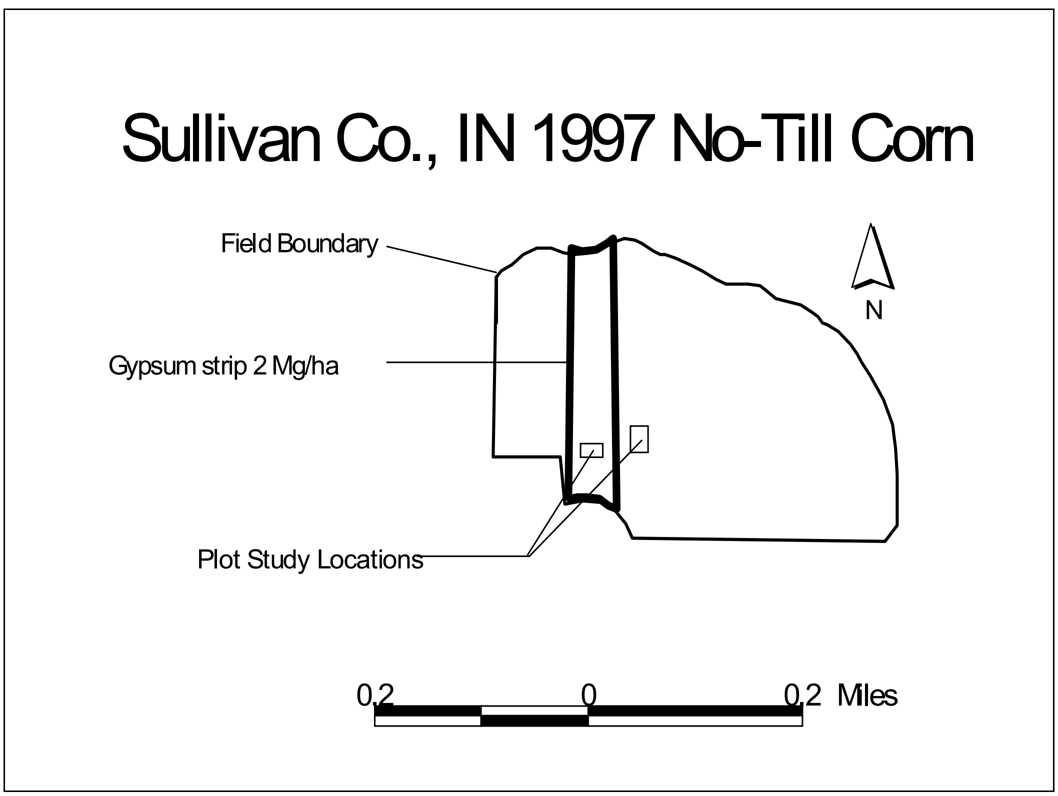

Figure 1. Sullivan County, IN location site for field study. Depicts outline of field, outline of gypsum surface applied gypsum strip, along with location of gypsum plot study. Field size is approximately 22ha. Gypsum surface applied at 2 Mg ha^{-1}

Table 2. Chemical Composition of flue desulfurization by product gypsum of four samples including Resource Conservation and Recovery Act standards and permit limits of these elements.

	Element	Sample Number 1	2	3	4	Range in Variability	Permit Limits
		mg kg^{-1}					
RCRA Metals	Arsenic	<3.3	4.7	<3.3	<3.3	<3.3 - 4.7	41.0
	Cadmium	<0.3	0.4	<0.3	<0.3	<0.3 - 0.4	39.0
	Chromium	6.6	6.9	8.4	7.4	6.6 - 8.4	no limit
	Lead	<3.3	<3.3	<3.3	4.2	<3.3 - 4.2	300.0
	Nickel	1.9	4.5	6.0	5.8	1.9 - 6.0	420.0
	Selenium	2.99	4.58	2.4	1.0	1.0 - 4.58	100.0
	Mercury	<1.7	2.8	2.1	2.3	<1.7 - 2.8	17.0
Other Elements	Copper	7.8	9.9	10.8	10.1	7.8 - 10.8	1500.0
	Molybdenum	<0.3	1	0.7	0.8	<0.3 - 1.0	no limit
	Zinc	13.8	8.9	11.3	12.6	8.9 - 13.8	2800.0
	Phosphorus	39.3	31.5	46.5	45.3	31.5 - 46.5	no limit
	Ammonium-N	6.6	6.3	<6.3	<6.3	<6.3 - 56.0	no limit
	Sodium	54.9	67.4	97.5	63.9	54.9 - 97.5	no limit
	Magnesium	184.5	175.9	384.1	474.6	175.9-474.6	no limit
	Potassium	352.1	337.3	396.2	375.4	337.3 - 396.2	no limit

to compute soil and water losses.

RESULTS AND DISCUSSION

Gypsum has been used for decreasing and preventing crust formation on soils surfaces and improving its water infiltration ability has been proven beneficial in previous studies on sodic or acid soils (Agassi et al., 1981; Miller, 1987). The results of this study also showed that the use of synthetic gypsum as a soil amendment was beneficial when surface applied in agricultural fields on Indiana loess derived soils.

The plot research was conducted on Iva Silt Loam soils, which are somewhat poorly drained soil according to the Soil Survey of Sullivan County (USDA, 1971). Infiltration rates effectively increased on the tilled plots with gypsum application (Fig. 2). The tilled plots had significantly greater total infiltration amounts using a t-test at the 0.05 level (Fig. 3). The no-till treatment was not expected to be different since it had already been subjected to low electrolyte rainwater and the surface compacted.

Gypsum has the ability to increase the hydraulic conductivity of the soil surface by preventing dispersion of the clay sized particles, which consequently slows the process of aggregate destruction and surface sealing. The infiltration rates of a soil are dominated by two mechanisms: physical and chemical processes (Norton, 1995). For the physical aspect, infiltration rates are affected by particle destruction impact during a rainstorm. The raindrop impact causes breakdown of soil aggregates which then creates a layer of finer aggregates. This mechanical process can largely be controlled with the use of residue cover (Reichert, 1996). Residue cover can reduce the raindrop impact by providing a protective cover over the soil surface which intercepts the raindrops and allows greater water infiltration into the undisturbed soil. The chemical processes that dominate infiltration rates are the electrolyte concentration (EC) of rainwater at the surface and the ionic composition of the exchange complex. A high EC at the soil surface keeps the clays flocculated, therefore, preventing a seal formation. The Diffuse Double Layer Theory (DDLT) (Van Olphen, 1977) explains the reaction that occurs when gypsum interacts with rainwater of irrigation water on the soil surface. Most soils (i.e. clays) have a net negative charge, and a balance is maintained in which the positively charged cations in solution create equilibrium. Dissolution of gypsum in this system reduces the diffuse layer radius surrounding clay, by release of electrolyte, and strengthens the ‘double layers’ which keeps clays flocculated. Dispersion is counter-acted when a cation with a higher opposing charge, such as Calcium a bivalent cation, causes the compression of the double layer and an increase in the ionic strength near the surface of the particles. Clay dispersion is minimized, therefore, keeping the surface pores open and allowing greater quantities of water to enter the soil. By using soluble gypsiferous materials, the chemical process of seal formation is greatly reduced through release of electrolytes.

Infiltration rates on no-till plots, where the residue was removed, didn't show any significant effects from gypsum application since the soil was already crusted. The physical raindrop impact didn't affect aggregate dispersion as much as tilled plots because long term no-till practices stabilized the soil and held the particles together. This strengthened soil surface was able to resist erosion to a greater degree than in the tilled plots. The tilled plots benefited from the gypsiferous materials by increasing the EC of the soil surface therefore, its chemical properties were affected. For the no-till plots, due to the soil strength, the physical properties continued to dominate infiltration rates and the chemical aspect didn't greatly affect the infiltration properties.

Total soil loss was also examined, and similar results were obtained as for infiltration. Tilled plots demonstrated a greater benefit from the FGD amendment with a 55% decrease in soil loss per plot area. No-till plots were not significantly different. Soil loss is related to infiltration rates, and when infiltration is high, soil loss is minimal.

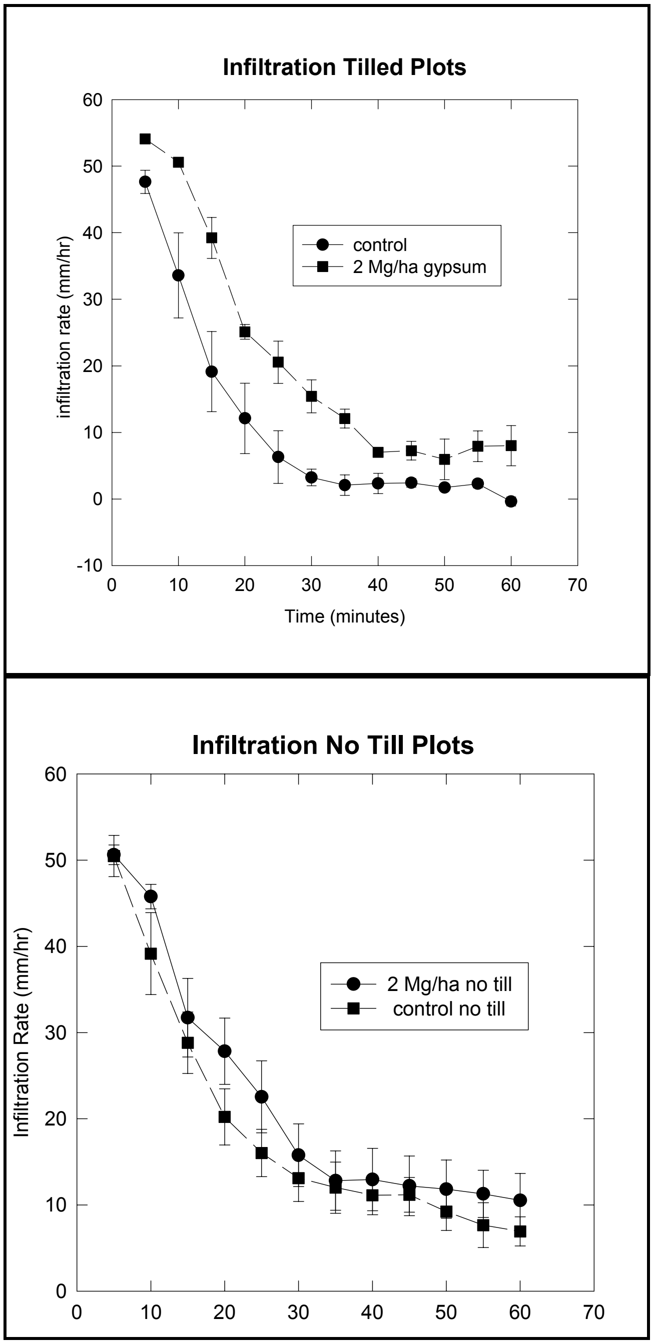

Figure 2. Infiltration Rates for a) Till and b) No Till plots in Sullivan County, IN. Gypsum was surface applied 2 Mg ha^{-1}. Plot location on Iva soil series.

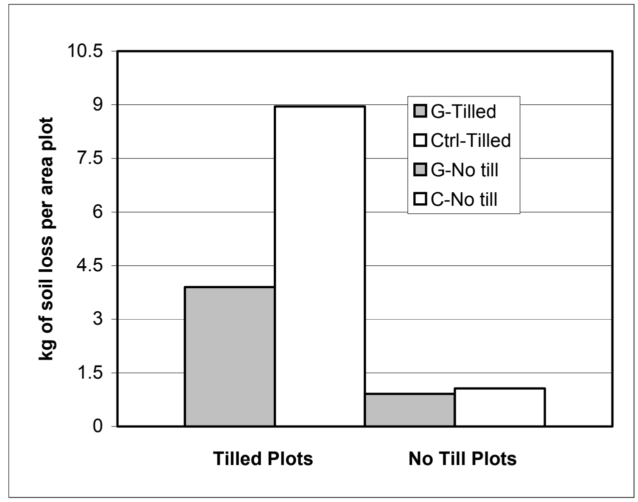

Figure 3. Total soil loss in kg per area plot. Gypsiferious materials applied at 2 Mg ha^{-1} in treatment area. The letters above the filled columns signify results of the t-test at the p>0.05 level. The same letter signifies no difference at this level.

CONCLUSIONS

Different tillage treatments were tested under simulated rainfall. In a corn and soybean field, with crops and surface residue removed, a rainfall simulator was setup over plots in order to collect sediment, infiltration, and runoff data. The study began with the crops well established in the field and the dry field conditions resulted in soil erosion parameters influenced statistically. Tillage also played a significant role in erosion and infiltration rates. Over all, the no-tilled plot measurements had less soil loss, and higher infiltration rates than the tilled plots.

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