CONSERVATION INNOVATION GRANTS

FINAL REPORT

COVER PAGE

DATE OF SUBMISSION: JANUARY 5, 2015

Grantee Name: UNIVERSITY OF MARYLAND EASTERN SHORE	
Project Title: Gypsum Curtains: Reducing soluble phosphorus (P) losses from P-saturated soils on poultry operations	
NRCS Agreement Number: 69-3A75-10-126	
Project Director: Arthur L. Allen	
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Period Covered by Report: 10/1/2010-10/10/2014	
Project End Date: 10/10/2014	

DELIVERABLES

1. Implement and demonstrate the effectiveness of gypsum curtains for reducing soluble P on farms.
2. Develop a practice standard for installation of gypsum curtains.
3. Conduct and document the results of a field day and/or workshop to demonstrate the technology.
4. Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.
5. Semi-annual performance progress report and a final report with quantified results of water quality sampling and monitoring activities to support the introduced technology/approach.
6. Develop a science based fact sheet showing how Gypsum curtains/filters reduce soluble P concentrations percentages in relation to flow rate and associated cost.

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Executive Summary

NRCS designated priorities

This project was designed to address the NRCS priority need to develop and evaluate conservation practices to control dissolved phosphorus export from ditch drained agriculture.

Goals and objectives

The overall goal of the project was to implement and evaluate on-farm strategies for using flue gas desulfurization (FGD) gypsum to sequester dissolved phosphorus and reduce its movement from crop fields to agricultural drainage ditches. Gypsum is a relatively soluble mineral that supports a high concentration of dissolved calcium which precipitates with phosphate to form the relatively less soluble calcium phosphate (less soluble than gypsum). FGD gypsum that is produced by modern forced-oxidation wet systems after the removal of fly ash is a very pure product that is readily available and free of elemental impurities at concentrations that would be of environmental concern.

Project Objectives:

1. Implement and demonstrate the effectiveness of gypsum curtains (permeable reactive barriers) for reducing soluble phosphorus on farms in Somerset County, Maryland, a key poultry producing region on the Eastern Shore of the Chesapeake Bay
    a. Demonstrate effectiveness at a sub-watershed scale
    b. Demonstrate effectiveness across different soil types in the region
    c. Evaluate potential adverse environmental impacts
2. Implement and demonstrate the effectiveness of surface application of FGD gypsum for reducing soluble phosphorus
3. Obtain producers' evaluations of these practices in the context of whole farm operations and adjust the practice to address producers' concerns if necessary
4. Work in concert with NRCS personnel and other entities to develop a conservation practice standard for the beneficial use of FGD gypsum in agriculture

Major accomplishments

Gypsum curtains were installed on all ditches at three farms owned by Steve Cullen and on selected tile drains on a fourth farm owned by Coulbourne Swift near Crisfield, MD. Gypsum curtains intercepted ground water that transported dissolved phosphorus (P) to drainage ditches and tile drains, and removed P by precipitation with calcium. A surface application trial was established in which gypsum applied at rates of 0, 2, 4, and 6 tons per acre quantified the effects on dissolved phosphorus (P) and on infiltration and drainage. Producers land applied gypsum on other fields on these farms at rates prescribed by nutrient management specialists.

As proposed, Constellation Energy (now Raven Energy) delivered 20,000 tons of gypsum to the research site for use by this project. The gypsum was valued at $15 per ton plus $35 per ton for transport for a total cost of $1 M. A local contractor provided curtain installation services and developed a highly efficient method for trenching, filling, and covering the curtains. The project also provided resources to allow continued monitoring of ditch curtains that were installed in August, 2009.

On May 23, 2012, a field day was conducted on Steve Cullen's farm. The purpose for installing gypsum curtains was explained and the method of installation was demonstrated. Approximately 30 people attended the field day. The audience included producers, Constellation Energy personnel, agency personnel from Natural Resources Conservation Service, Maryland Soil and Water Conservation District, MDE, MDA, scientists from several Land-Grant Institutions (UD, UMD, UMES), and graduate and undergraduate students.

Two subsurface imaging training workshops were conducted at the UMES Campus in 2014. Participants included 16 scientists, and three graduate students from Penn State, Univ. of Delaware, USDA-ARS, and Rutgers University (trainers). Field deployment of electrical resistivity imaging (ERI) instrumentation and computational training focused on groundwater and nutrient movement from field to ditch in the vicinity of gypsum curtains.

This project resulted in completion of a Master's degree by a student studying at the University of Maryland, College Park. The project provided research internship training for six undergraduate students at various stages of matriculation at the University of Maryland Eastern Shore.

Project data and results were presented as posters and oral presentations (available if needed) at meetings of the American Society of Agronomy, Association of Research Symposium, and the Soil and Water Conservation Society. Co-PI's Ray Bryant and Arthur Allen served as Leaders of the American Society of Agronomy By-product Gypsum Uses in Agriculture Community in 2013 and 2014 respectively. They organized and presided over a joint symposium on the "Science behind a Conservation Practice Standard for Gypsum Soil Amendments" at the 2014 meetings of the American Society of Agronomy in Long Beach, CA. The session included 11 invited speakers and was attended by more than 200 scientists.

Co-PI's Arthur Allen and Ray Bryant led the development of a conservation practice standard titled *"Amending Soil Properties with Gypsum Derived Products"* in concert with the American Society of Agronomy By-product Gypsum Uses in Agriculture Community. Over 70 scientists from the international community participated in writing and reviewing the standard via a list serve. This document was presented to the NRCS Agronomy Team for review and input in December, 2014.

Completion of goals and objectives

All goals and objectives were met or substantially met. Monitoring groundwater chemistry in an actively managed field proved difficult. The process of burying access tubes for drawing water from buried piezometers resulted in a disturbed soil zone that allowed calcium rich water to move from the curtain to the buried piezometer on the field side of the curtain. The calcium enriched water precipitated dissolved P. As a result, we did not measure elevated concentrations of dissolved P coming from the field as was expected in these high P soils. Therefore, we could not document P reductions across the curtain at the on-farm sites. However, monitoring data from wells installed on the gypsum curtains on the UMES Research and Teaching Farm in 2009 did continue to show very effective P reductions five years after installation. Information derived from on-farm installation of gypsum curtains proved valuable for determining costs of commercial installation and producers' assessments.

In addition to the original project objectives, hurricane Sandy provided an opportunity to demonstrate the effectiveness of applying gypsum to correct salinity in soils that were flooded by high tides.

Timeframe for project completion

Principal Investigators requested and were granted a *one-year* extension to complete this project. While this proposal was under consideration for funding, EPA released new proposed rules for regulating coal combustion residuals. Under one proposed set of rules, all residuals, including FGD gypsum, would be regulated as toxic waste requiring disposal in a Class- C lined landfill. Certain beneficial uses, such as in making wallboard, would be allowed, but continued use for agricultural was being debated. We notified NRCS project liaisons of this situation and were advised to proceed cautiously pending the anticipated final EPA ruling. In year one, we worked with Maryland Department of Agriculture and Maryland Department of the Environment to obtain permission to proceed with the project. We also established other agreements and contracts that facilitated cooperation among project partners. Due to this delay in implementing the practice, we requested and were granted a *one-year no-cost extension* to complete this project.

Customers

Local producers reaped soil improvement, agronomic, and economic benefits from receiving gypsum for use as a soil amendment. They observed improved soil infiltration and drainage. They were in need of a calcium source to raise soil calcium levels without raising pH. They were able to save on fertilizer costs by not having to apply sulfur. They used high rates of gypsum to correct salinity and restore productivity to soils that were flooded by high tides during hurricane Sandy.

The Maryland Department of Agriculture and Maryland Department of the Environment used results from this project to guide their decision to permit the utilization of FGD gypsum for use in agriculture.

Constellation Energy/Raven Power benefitted by gaining an agricultural market for FGD gypsum produced in Baltimore.

Scientists, graduate students, various agricultural agencies, and the agricultural community as a whole benefitted as this project resulted in the development of a Conservation Practice Standard for *"Amending Soil Properties with Gypsum Products"*.

Use of project funds

We had a balance remaining due to our decision to purchase a relatively low cost trailer style Side-Shooter rather than a more expensive self-propelled machine that appeared in the original budget, *a wiser use of funds*. Due to these saving, we purchased an Electrical Resistivity Imaging (ERI) instrument ($90,000) to study groundwater flow paths, a Lachat 8000 Flow - Injection Nutrient Analysis System ($50,000) to expand nutrient analysis capabilities, and a premium YSI meter ($19,000) used for field site chemistry and nutrient analyses.

Methods employed to demonstrate alternative technology

An edge- of- field reactive barrier called Gypsum Curtain (3- 5 feet deep and 1-foot wide) was designed to trap dissolved P prior to groundwater movement to drainage ditches. We demonstrated the effectiveness of surface application of gypsum for sequestering dissolved P as insoluble calcium phosphate and reducing losses in runoff.

Quantifiable physical results

Gypsum Curtains: The mean reduction in dissolved P concentrations across the gypsum curtains was 88% and the median was 91%.

Surface Application: One year after application, there was a slight reduction (15%) in water soluble phosphorus concentration in soils amended at the 2 tons per acre rate. There was a 35% and 50% reduction in water soluble phosphorus concentration in soils amended at the 4 tons and 6 tons per acre rate respectively.

Economic results

Gypsum Curtains: The cost of construction, including excavation, handling the gypsum and filling the trench, and backfilling was $2.50 per linear foot. The cost of the gypsum is $2.50 per linear foot, not including the cost of transporting gypsum from the power plant to the farm. The cost of transportation represented the greatest cost of gypsum curtain installation, but these costs could be greatly reduced if large quantities of gypsum could be transported to the Eastern

Shore by barge. Raven Power can ship by barge, and several ports exist in Somerset County, MD.

Surface Application: Poultry litter spreaders were used to surface apply gypsum; no specialized equipment is needed. The producers we worked with own tractor trailers and are capable of taking delivery at the power plant at a cost of $15 per ton. As one producer explained, transportation cost by truck is minimized when gypsum can be back hauled after delivering a load of wheat to markets in Pennsylvania. This producer has requested additional gypsum at his own expense. This proves that the practice of surface application is economically viable.

Implementation programs

Once the conservation practice standard is officially adopted, the agricultural use of gypsum derived products as prescribed in the standard will be implemented through NRCS state offices with technical support from Soil and Water Conservation Districts. In regard to the use of FGD gypsum, State Departments of Agriculture and Departments of the Environment should be contacted for approval since FGD gypsum is regulated by the Environmental protection Agency. However, EPA has expressed approval for the beneficial use of FGD gypsum in agriculture, and states should be supportive.

Major recommendations

From a resource conservation perspective, surface application of gypsum is an effective and economical practice for protecting water quality by reducing dissolved P losses in runoff and in groundwater pathways. It can also ameliorate subsoil acidity, improve infiltration, and reduce pathogen losses. From an agronomic perspective, surface application of gypsum is a source of calcium and sulfur and can be used to correct sodicity. We recommend formal adoption of the conservation practice standard for surface application of gypsum derived products.

Gypsum curtains are an effective edge-of-field technology for reducing dissolved P movement to drainage ditches via groundwater pathways. However, using gypsum in this fashion does not have the added benefits afforded by surface application, and it is considerably more expensive. Gypsum curtains should be reserved for extreme cases where P losses cannot be effectively controlled by surface application. Developing a separate practice standard for gypsum curtains should be considered. Gypsum curtains were excluded from the current draft standard because the practice requires special engineering criteria, such as trench depth, width, etc., which would have complicated development of a standard for surface application.

Introduction

The Gypsum Curtain Project explored strategies for using flue gas desulfurization (FGD) gypsum to reduce dissolved phosphorus (P) losses from high P soils (legacy sources) on the Delmarva Peninsula. Soil scientists and co-principal investigators, Dr. Arthur Allen, University of Maryland Eastern Shore (UMES), and Dr. Ray Bryant, USDA-ARS at University Park, PA, had demonstrated effective reduction of dissolved P in groundwater after passing through a gypsum-filled trench adjacent to an agricultural drainage ditch on the UMES Research and teaching Farm. An NRCS-funded Conservation Innovation Grant in the amount of $1 million was funded to develop commercial scale installation methods, determine costs and benefits, and evaluate producers' acceptance of the practice in on-farm trials. Under the terms of a cooperative agreement, Constellation Energy (now Raven Energy) delivered 20,000 tons of gypsum from its Brandon Shores power generation plant near Baltimore, MD to the Eastern Shore study site near Crisfield, MD for use by this project. The gypsum was valued at $15 per ton plus $35 per ton for transport for a total match of $1 M.

The research team also included Dr. Peter Kleinman, ARS Soil Scientist/Research Leader, Dr. Anthony Buda, ARS Hydrologist, and Dr. Gary Felton, University of Maryland Soil Physicist (See brief vitas in Appendix A). Under a subcontract with the University of Maryland at College Park, Ms. Loretta Collins, graduate student, completed a Master's degree and led studies on the effects of surface application of gypsum. Mr. Gary Fykes, Somerset County Soil and Water Conservation District Manager, collaborated on the project to identify cooperative producers. Mr. Salil Bose, Constellation Power Generation, served as the initial industry representative on the project. Mid-way through the project the power plant was sold to Raven Power, and Ms. Anne Cowenhoven subsequently served as the industry representative. The project was conducted on three farms in the Crisfield area that are owned and operated by Mr. Steve Cullen and one farm owned and operated by Mr. Coulbourne Swift. Mr. Alfred Bradford, local contractor, provided curtain installation services under a series of contracts with UMES.

The project was approved for funding in July 2010, but activities were delayed for one year due a provisional ruling by EPA that would potentially classify FGD gypsum as a toxic waste. The co-principals negotiated permissions to proceed with the project with their respective organizations and with the Maryland Department of Agriculture and Maryland Department of the Environment (See Appendix B). A one year no-cost extension was granted and the project was successfully concluded in 2014. In December 2014, EPA issued a final rule to regulate the disposal of coal combustion residuals as non-toxic waste under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The ruling supports the beneficial use of FGD gypsum in agriculture.

Goals and Objectives

The overall goal of the project was to implement and evaluate on-farm strategies for using flue gas desulfurization (FGD) gypsum to sequester dissolved phosphorus and reduce its movement from crop fields to agricultural drainage ditches. Gypsum is a relatively soluble mineral that supports a high concentration of dissolved calcium which precipitates with phosphate to form the relatively less soluble calcium phosphate (less soluble than gypsum). FGD gypsum that is produced by modern forced-oxidation wet systems after the removal of fly ash is a very pure product that is readily available and free of elemental impurities at concentrations that would be of environmental concern (See laboratory analyses of FGD gypsum in Appendix C).

Project Objectives:

1. Implement and demonstrate the effectiveness of gypsum curtains (permeable reactive barriers) for reducing soluble phosphorus on farms in Somerset County, Maryland, a key poultry producing region on the Eastern Shore of the Chesapeake Bay
    a. Demonstrate effectiveness at a sub-watershed scale
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Project Scope

Under the scope of this project, 20,000 tons of FGD gypsum was delivered to the farms and stored in manure stacking sheds until used for curtain installation or surface application. Gypsum curtains were installed within agricultural fields adjacent to all open ditches on three farms in the Crisfield, MD area. Gypsum curtains were also installed adjacent to newly installed tile drains on a fourth farm (See farm conservation plan maps in Appendix D). Total estimated length of trench on all farms was approximately 80,000 feet of curtain. In addition, a surface application trial was conducted in which the effects on dissolved P and infiltration rate were assessed at application rates of 0, 2, 4, and 6 tons per acre.

Background

The Delmarva Peninsula houses a robust poultry industry that has been scrutinized for its contributions of nutrients to the Chesapeake Bay. UMES and USDA-Agricultural Research

Service (ARS) researchers have documented substantial P concentrations in agricultural drainage waters derived from high P soils (350 to 550 mg kg^{-1} Mehlich-3 P) that have received poultry litter for decades. Even when these soils receive no P additions, losses due to soluble P moving through groundwater result in P concentrations in ditches of 2 to 4 mg L^{-1} (Kleinman et al., 2007; Vadas et al., 2007; Kleinman et al., 2009). Changes in nutrient management, including no future P inputs to these high P soils, will not appreciably reduce soluble P concentrations from these legacy P sources. This is especially true for sandy soils on flat landscapes of the Eastern Shore where downward leaching and lateral flow of water containing high concentrations of soluble P is the dominant pathway of P movement from field to drainage ditch.

Scientific evidence that dissolved P movement is a significant pathway for movement to drainage waters is relatively recent, and effective means of controlling dissolved P losses have not been developed. Existing conservation practices, such as minimum tillage and edge-of-field grass filter strips, are designed to reduce sediment-bound, particulate P in runoff and offer no control over dissolved P losses in groundwater flow. The first ditch filter (figure 1), in which gypsum was used to precipitate dissolved P in ditch flow, was constructed and monitored at UMES as an *earlier practice* for reducing dissolved P losses. The ditch filter has been shown to effectively reduce dissolved P in ditch flow by 50 to 90 percent depending on flow rate (Bryant et al., 2012).

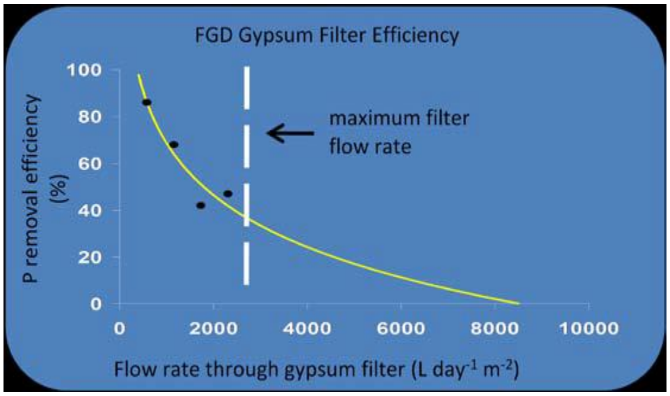


Figure 1. Gypsum filter reduces soluble P concentrations by 50 to 90% in relation to flow rate.

The gypsum filter and other filtration approaches were further evaluated in on-farm trials under a $1 million Conservation Innovation Grant awarded to Dr. Josh McGrath at the University of Maryland (Penn et al, 2012). Although in-ditch filtration may be well suited for some situations, the practice has limitations. Construction involves the burial of tile drains and construction of a stable dam and spillway. The filter requires frequent inspection and possible repair to prevent structural failure and loss of the gypsum into surface waters. Most importantly, large flow events, which transport most of the P load, over flow the spillway and bypass the filter, thus, limiting the overall effectiveness of the practice.

Gypsum curtains represent the next generation of filtration approaches whereby lateral groundwater flow is effectively treated even under high ditch drainage volumes and flow rates, while maintenance requirements and interference with agricultural practices are minimized. Based on the relationship between flow rate and P removal efficiency (figure 1), we expected relatively high P removal efficiency as lateral groundwater flow rates are considerably slower. Preliminary results from a pilot study in which curtain segments were installed on the UMES Research and Teaching Farm confirmed P removal efficiencies ranging from 75 to 95%.

This project sought to test this edge of field groundwater filtration technology (gypsum curtains) in an on-farm environment to determine producer acceptance of the practice and establish the economic feasibility of this method of controlling dissolved P losses. In addition, we sought to evaluate the effects of surface application of FGD gypsum on dissolved P and the effects on infiltration that could potentially decrease runoff and increase the volume of groundwater moving through the curtains.

Gypsum curtains are best suited for addressing dissolved P losses from high P soils under ditch drained agriculture on flat landscapes. The practice is well suited for Coastal Plain areas such as the Eastern Shore. Water quality of streams, rivers and the Chesapeake Bay are impaired by excess P, and gypsum curtains are an effective, long-lasting, one-time treatment for effectively reclaiming soils affected by legacy P. Although there are no direct economic benefits, producers who are under intense pressure to reduce P losses to surface waters are potential beneficiaries, as well as state, county, and local agencies that are tasked with cleaning up the Bay.

Surface application of gypsum also effectively reduces dissolved P losses, but requires repeated treatment under a long-term maintenance program. Surface application also has beneficial agronomic effects that afford direct economic benefits to producers, making it a more attractive option.

The cost of not addressing dissolved P losses in this agricultural area on the shore of the Chesapeake Bay is impaired water systems, poor soil health, reduced tourism due to pollution fears, economic survival of Watermen, additional cost to farmers associated with meeting TDML’s and other nutrient management imposed regulations by State agencies.

Methods

Upon initiation of the project, stream and ditch monitoring in the study area was intensified in in an effort to establish a base line for assessing the effectiveness of this practice. Following several months of monitoring, gypsum curtains were installed by a local contractor, and stream and ditch monitoring methods were used in an attempt to measure changes in groundwater, ditch and stream chemistry following filtration.

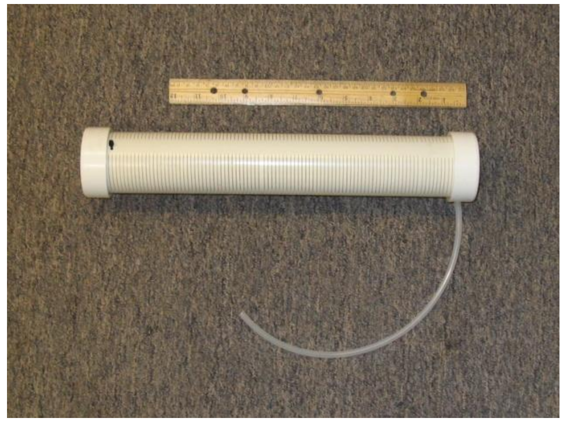
The goal of the landscape hydrology component of this study was to provide a mechanistic understanding of groundwater hydrology that drives stream flow so nutrient loads can be calculated. Existing regional weather stations in the study area provided climate data for the region. Piezometers were installed within and at edge of fields to monitor depth to groundwater, determine groundwater flow paths and seasonal groundwater response to precipitation events. Flumes were installed on select ditches to gauge ditch flow and seasonal response to precipitation events in the context of groundwater flow characteristics. Flow gauges and electrical resistivity imaging (ERI) techniques were used to monitor ditch and stream response to precipitation events that drive agricultural drainage in the study area.

The goal of the water quality monitoring component of this study is to characterize soluble P transport within the study area. Piezometers were installed at edges of fields in selected areas. Automated samplers and manual sampling techniques were used to collect water samples in piezometers, at flumes in ditches and along stream channels. Water samples were collected by UMES personnel, filtered in the UMES Nutrient Analysis Laboratory and shipped to University Park, PA for analysis. The USDA-ARS Water Quality Laboratory at University Park, PA conducted all water analyses by inductively coupled plasma optical emission spectrometry (ICP-OES) to measure Al, Ca, Cd, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, and Zn. The primary elements of environmental concern, mercury (Hg) and arsenic (As) were measured at detection limits of 1 ug L^{-1}. Standard QA/QC practices, such as internal standards and replicate measurements that are routinely used by both laboratories were followed.

Following installation of gypsum curtains, piezometers were installed on both sides of the curtains to monitor P reductions across individual curtains, especially during high flow events when near surface groundwater is in contact with plowed horizons and P concentrations are highest.

Successes and Failures

The equipment and methods used for installation of gypsum curtains were very successful and an efficient process resulted in the lowest possible cost of installation. The pull-behind *Sideshooter* used to delivered gypsum to the trench cost much less than the self-propelled model that we originally proposed to buy (photo below, left). A tractor with a hydrostatic drive proved ideal for delivering the right amount of gypsum to the trench and would generally be available for use on most farms. The producer did allow the contractor to use his tractor for this purpose at no cost to the contractor or the project. Initial problems with the *Sideshooter* slipping into the trench when the bank caved were eliminated by modifying the *Sideshooter* with a longer side delivery shoot. A trencher with a one foot wide belt and a crumbler proved to be the fastest means of excavation. One operator was able to fill the trench using the tractor and *Sideshooter* and cover it using a skid steer and maintain the same pace as the trencher operator.



In an attempt to monitor groundwater on both sides of the curtains installed in producers' fields, we developed a small piezometer that could be buried and accessed for sampling via a buried tube that extended laterally to the ditch (photo above, right). Although we were able to collect samples, the soil disturbance that occurred during burial of the sampling tube allowed groundwater to move from the curtain toward the field side piezometer. This was evidenced by uncharacteristically high calcium concentrations in samples drawn from the field side piezometer. Consequently, dissolved P concentrations were low and did not represent dissolved P concentrations in the high P soils that we sought to characterize. For this reason, on farm data were not used to characterize the effectiveness of the curtains. Instead, we relied on measurements taken from the curtains installed on the UMES Research and Teaching Farm where piezometers were not buried, but instead could be accessed and sampled from the top.

Findings

UMES Ditch Curtain Data Summary

Project activities included continued monitoring of ditch curtain segments adjacent to an agricultural field drainage ditch and the curtain that is adjacent to the Manokin Branch on the UMES Research and Teaching Farm that were installed in August, 2009. The data in Table 1 are from 7 sampling events when the water table was near the surface in 2013 and the first half of 2014, three and a half to five years after installation. A recent excavation across a ditch curtain shows conditions very similar to those at the time of installation. There is little evidence of change in the condition of the curtain over the five year period.

A total of 2610 samples were characterized, but these included samples from wells at 1, 2.5, 4, and 7 foot depths (raw data available upon request). Ditch curtain samples generally contain less than 0.1 mg/L at depths below 2.5 feet. Manokin curtain samples from shallower than 4 feet are rare because the channel depth draws the water table down sharply near the channel. However, some of the highest P concentrations were observed in samples from the 4 foot wells

Table 1. Gypsum curtain data from the UMES Research and Teaching Farm four years after installation.

Lab id	Ditch Curtains Well Depth		Date	Before P (mg/L)	S (mg/L)	After P (mg/L)	S (mg/L)	Reduction %	Before As (mg/L)	Before Hg (mg/L)	After As	After Hg
19623	Well - 1 foot	Curtain 1	1/14/14	1.54	2.0	0.00	341.4	**100%**	0.002	ND	ND	ND
19680	Well - 2.5 feet	Curtain 2	1/14/14	0.52	13.6	0.00	378.5	**100%**	0.002	ND		
19969	Well - 1 foot	Curtain 2	3/20/14	1.70	7.8	0.03	272.1	**98%**	0.003	ND	ND	ND
18211	Well - 1 foot	Curtain 3	5/8/13	1.57	5.1	0.06	218.4	**96%**	0.004	0.002	ND	ND
18200	Well - 1 foot	Curtain 2	5/8/13	1.07	3.9	0.04	365.2	**96%**	0.005	0.002	ND	0.002
20216	Well - 1 foot	Curtain 3	4/1/14	2.45	5.4	0.11	281.0	**95%**				
20001	Well - 1 foot	Curtain 4	3/20/14	0.49	7.8	0.02	41.6	**95%**	0.002	ND		
20148	Well - 1 foot	Curtain 1	4/1/14	1.17	9.1	0.06	427.0	**95%**				
20228	Well - 1 foot	Curtain 4	4/1/14	0.80	3.9	0.05	325.3	**93%**				
19989	Well - 1 foot	Curtain 3	3/20/14	0.81	10.4	0.06	180.2	**93%**	0.002	ND	ND	ND
20264	Well - 1 foot	Curtain 7	4/1/14	0.71	3.1	0.06	52.2	**92%**	0.002	ND	ND	ND
20252	Well - 1 foot	Curtain 6	4/1/14	1.25	4.5	0.11	125.3	**91%**				
18632	Well - 1 foot	Curtain 2	6/12/13	1.80	5.3	0.16	385.5	**91%**	0.005	0.003	ND	
19977	Well - 1 foot	Curtain 2	3/20/14	0.38	17.9	0.03	424.5	**91%**	ND	ND	ND	ND
18657	Well - 2.5 feet	Curtain 3	6/12/13	1.05	12.8	0.11	376.5	**90%**	0.004	0.003	ND	0.003
20204	Well - 1 foot	Curtain 2	4/1/14	0.57	15.5	0.07	224.0	**88%**				
20188	Well - 1 foot	Curtain 2	4/1/14	1.11	9.8	0.14	265.8	**88%**				
19961	Well - 1 foot	Curtain 2	3/20/14	1.11	5.7	0.14	247.2	**87%**	0.002	ND	ND	ND
19530	Well - 2.5 feet	Curtain 3	11/27/13	1.02	4.2	0.13	271.2	**87%**	0.001	ND	ND	ND
20149	Well - 2.5 feet	Curtain 1	4/1/14	0.42	16.9	0.06	446.1	**86%**				
20205	Well - 2.5 feet	Curtain 2	4/1/14	0.44	17.6	0.07	366.5	**85%**				
19615	Well - 1 foot	Curtain 1	1/14/14	1.05	1.6	0.17	13.1	**84%**	0.003	ND	0.001	ND
19703	Well - 1 foot	Curtain 4	1/14/14	0.65	6.4	0.14	43.2	**78%**	0.002	ND	ND	ND
19691	Well - 1 foot	Curtain 3	1/14/14	1.90	2.9	0.44	253.3	**77%**	0.003	ND	ND	ND
20196	Well - 1 foot	Curtain 2	4/1/14	0.61	17.3	0.14	318.0	**76%**				
19540	Well - 1 foot	Curtain 4	11/27/13	0.66	9.4	0.20	45.7	**70%**	0.003	ND	ND	ND
20240	Well - 1 foot	Curtain 5	4/1/14	0.31	16.2	0.13	30.7	**58%**				

on the Manokin curtain. When samples contained less than 0.2 mg/L phosphorus, differences in P concentration in the before and after curtain samples were minimal. In order to see the effectiveness of P removal, this summary focuses on paired samples before and after samples from wells at the same depth that contained greater than 0.3 mg/L phosphorus in the before sample (Table 1). Thirty seven paired observations met these criteria for curtain segments, six paired observations occurred in the open control plots, and seven paired observations occurred in the curtain that was installed along the Manokin Branch.

The data were sorted by elemental sulfur content on the after side of the curtain (between the curtain and the ditch). The 27 paired observations shown on page 1 of Table 1 have greater than 30 mg/L elemental sulfur in the after curtain sample. High elemental sulfur content is evidence of dissolved gypsum that should effectively reduce dissolved P concentrations. With one exception, all of these high sulfur content sampled showed P reductions of greater than 70%. The mean reduction in dissolved P concentration was 88% and the median was 91%.

The 10 paired gypsum curtain observations shown on page 2 of Table 1 have less than 10 mg/L elemental sulfur content, indicating hydrologically isolated zones where there is no evidence of dissolved gypsum. These pairs had much lower P reduction (mean 32%) and were similar to the results observed in the open control plots (mean 50%). The UMES Farm does maintain a 10 foot grassed buffer strip adjacent to the agricultural ditches, and the observed reduction is apparently due to the absence of P additions near the ditch.

There are 8 paired observations from wells on the Manokin curtain (Table 1). Dissolved P reductions ranged from 13% to 97% (mean 55%, median 52%). All pairs showed high elemental P concentrations indicating the presence of dissolved gypsum.

In general, arsenic values are higher in the before samples (field side of the curtain) and are mostly non-detect on the after (ditch side of the curtain). The arsenate molecule is similar to phosphate and is being precipitated as calcium arsenate within the curtain. There are no apparent differences in mercury content between paired observations, and values are low to non-detect with a detection limit of 0.001 mg/L by ICP with hydride generation.

In conclusion, the gypsum curtains are providing significant reductions in dissolved P concentrations in groundwater five years after installation with no indication that they are near the end of their period of effectiveness. Arsenic is being sequestered in the curtain by calcium precipitation; the same process of that sequesters phosphorus. There is no difference in mercury concentrations due to the presence of the curtain, and most samples are below or near the EPA drinking water standard of 0.002 mg/L.

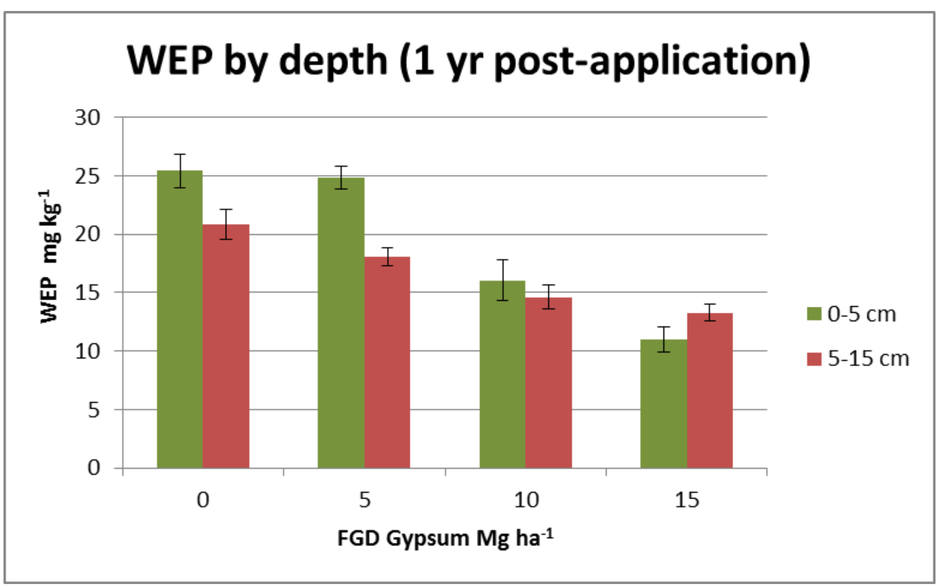
Surface Application

A surface application study was conducted by a University of Maryland graduate student on the Bradshaw Farm. In December 2011, Othello Fallsington, and Quindocqua soils (Typic Endoaquults) were amended with gypsum at rates of 0, 2, 4, and 6 tons per acre to assess the effects on soluble phosphorus and infiltration rate. The average pH at the site was 5.2 and the average Mehlich 3 phosphorus value was 384 mg kg^{-1}. The producer used his litter spreader to apply the gypsum. Specialized equipment was not required.

One year after application, there was a slight reduction (15%) in water soluble phosphorus concentration in soils amended at the 2 tons per acre rate (figure 2). There was a 35% and 50% reduction in water soluble phosphorus concentration in soils amended at the 4 tons and 6 tons per acre rate respectively. Reductions in water soluble phosphorus are due to precipitation with added calcium from dissolved gypsum; the same reaction as occurs in the gypsum curtain. However, unlike the gypsum curtains, the effects began to dissipate in years 2 and 3 when no additional gypsum was added. Under acid soil conditions (pH = 5.2), the calcium phosphate is gradually dissolved. By liming to near neutral pH and/or adding additional gypsum, the reductions in soluble phosphorus could have been sustained for a much longer period of time.

Infiltrometer measurements were made at several time intervals following gypsum application. Treatment effects were not statistically significant due to high variability and the limited number of replicate measurements, which are difficult and time consuming.

Figure 2. Water extractable soil phosphorus one year after gypsum application



Tile Drain Curtains

A study of the effect of gypsum curtains for reducing P losses in tile drain effluent was implemented on newly installed tile drains on the Coulbourne Swift farm (See Appendix D). Gypsum curtains were installed along the full length on both sides of select tile drains. Other drains were left untreated as controls. Although dissolved P concentrations in tile drain effluent have been shown to be a significant pathway for P loss in some soils, P concentrations in effluent from all tile drains in this study were low. There were no significant differences in dissolved P concentrations between treated and untreated drains. This result may have been due to the recency of tile drain installation that would have disrupted macropore flow, which is the primary pathway for P movement to the tile drains. We plan to continue monitoring the drains for several years to determine whether P concentrations increase over time in untreated drains as macropores redevelop under no till management and, if so, whether gypsum curtains result in decreased P losses.

Practical Considerations and Producer Input

Based on observations of phosphorus concentrations in groundwater at the UMES Research and Teaching Farm, our instructions to the contractor were to excavate a one foot wide trench to the depth of the bottom of the ditch. On average, that was equivalent to approximately 2.5 feet. The contractor initially used an excavator to dig the trench, but later bought a trencher with a one foot wide belt. The trencher was much more efficient. A tractor pulled *Mensch W3350 Sideshooter* was purchased at a cost of $26,000 and provided to the contractor for use in placing the gypsum in the trench. The *Sideshooter* was modified to shoot from a greater distance from the trench, and that alleviated a problem of the trench caving in due to too much weight close to the trench. A skid steer loader was used to load gypsum into the *Sideshooter* and replace topsoil to bury the gypsum. The cost of construction, including excavation, handling the gypsum and filling the trench, and backfilling was $2.50 per linear foot. That cost does not include the cost of the gypsum.

A trench of dimensions 1’ x 3’ x 6’ holds approximately one ton of gypsum. One ton of gypsum is valued at $15 at the power plant. The costs of transportation from Brandon Shores, MD to Crisfield, MD was $35 per ton under a contract negotiated by Constellation Energy, but there was no back haul. In practice, transportation costs could be much lower. The possibility of transport by barge was explored, but arrangements with a suitable dock could not be reached for this short term project. Transport by barge would greatly reduce the costs.

Cost per acre is dependent on the size and shape of the field and presence of ditches along field boundaries. On the Bradshaw Farm, curtains were installed on 16,324 feet of ditches surrounding 54 acres of farm fields at a cost of $5 per linear foot, which includes construction and cost of gypsum at the power plant, but not transportation. That equates to a cost of approximately $1500/acre, which is comparable to land reclamation costs. Including transportation costs could double this figure. Since the practice should last for decades with little or no maintenance cost, it seems fair to compare this practice with other land reclamation practices.

The producers did not have any complaints in regard to installation as all work was done when the fields were fallow. One producer commented that he expected to see two rows of dead soybeans next to the ditch where he planted over curtains. However, soybeans growing over the curtain grew better than before. We attributed this observation to the fact that gypsum is hygroscopic, and the buried gypsum improved the available water compared to edge of ditch areas without curtains where excessive drainage results in droughty conditions.

The producers were most pleased with the opportunity to surface apply gypsum. Although our initial purpose was to reduce water soluble phosphorus and lower phosphorus losses in runoff, the producers saw an opportunity to supply sulfur and not have to buy sulfur fertilizer to raise calcium levels in soils that had high pH without raising pH to excessively high levels by applying lime. Producers did comment that they observed less surface ponding and an apparent increased infiltration rate in gypsum amended soils. Although attempts to quantify an increase in infiltration rate using infiltrometer measurements did not show significant increases due to extreme variability, this visual observation does support the expected resulting improvement in soil physical characteristics.

Some fields on Steve Cullen’s farm were flooded with seawater for several days following hurricane Sandy in October, 2012. Following recommendations made by his nutrient management advisor, he applied gypsum at 6 tons per acre to correct for saline/sodic conditions. Although the small grain crop was lost that year, the soils were productive again the following year. A serious economic loss was averted.

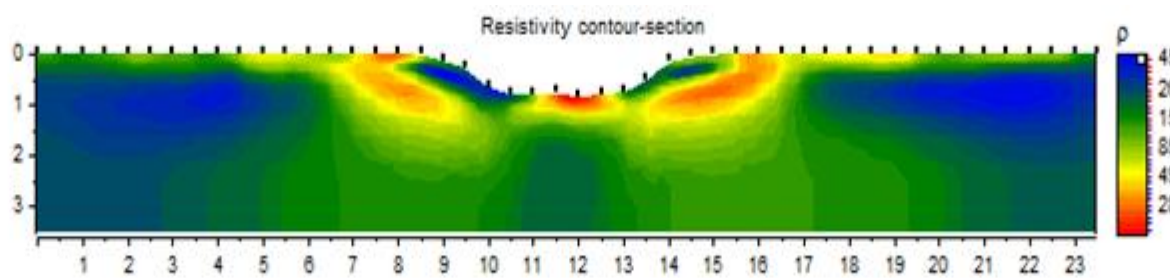
Sulfate Movement to Surface Waters

Sulfate in aqueous sediments can play a role in mercury methylation. Sulfate is generally found in brackish and marine waters. At sulfate concentrations typical of full marine conditions, sulfate does not facilitate mercury methylation, and in fresh waters where sulfate concentrations are low it does not play a role in mercury methylation. However, at intermediate concentrations, sulfate can facilitate the microbial process of mercury methylation, which is a potential environmental concern. The release of sulfates into the Florida Everglades is restricted, because atmospheric deposition of mercury has resulted in significant levels in aquatic sediments. If the mercury in those sediments were to be converted to toxic methyl mercury, it would be of concern to aquatic life. However, the Everglades are one of very few areas where this concern exists. The environmental impact of introducing of gypsum to any ecosystem should be assessed prior to implementation.

Sediment samples were taken along the main stem of the Manokin River from non-tidal fresh water areas to the open Bay. As expected, sulfates in these samples ranged from very low in the fresh water sediments to concentrations typical of full marine conditions in the Bay, with intermediate sulfate concentrations in the brackish tidal zone (data not shown). Hypothetically, addition of sulfates to this channel would drive the intermediate sulfate concentration zone farther upstream where the channel width is narrower. Therefore, the total area of channel sediment exposed to intermediate sulfate concentrations that could potentially facilitate mercury methylation would be reduced. However, sediments were also digested and analyzed for total mercury content, and mercury was below the detection limit. Mercury methylation is not an issue of concern in the Manokin River system.

Although mercury methylation was not a concern in our area, we did study the fate of sulfate associated with gypsum curtain installation. Electrical Resistivity Imaging (ERI) was used to investigate subsurface movement of gypsum in the vicinity of the curtains. The images clearly show low resistivity (high electrical conductivity indicating the presence of salts in the form of dissolved gypsum) where the gypsum curtains are located and suggest that dissolved gypsum is migrating toward the ditch near the bottom of the curtains (figure 3). The bottom of the ditch also shows low resistivity/high conductivity.

Figure 3. Electrical Resistivity Image showing dissolved gypsum moving to the ditch.



Sulfates from gypsum curtains do move into drainage ditches and will eventually reach streams and, in our region, the Chesapeake Bay. Table 2 contains water extractable sulfate from sediments along a 100 meter stretch of the ditch upstream of the curtain segments, between each of the four pairs of curtain segments, and along a 200 meter stretch of the ditch downstream of the curtain segments.

In June, water was standing in the ditch in most sampling sites (Upstream 75 and 50 were semi-dry). Sulfate concentrations were low, indicating that sulfur was in a reduced state and strongly bound to iron. In July, conditions were drier and moderate levels of sulfate were extracted from all sites (dry/field moist). These field moist samples were allowed to air dry, which would result in oxidation of sulfur. When the dry sediments were rewetted, water extractable sulfur was low

Table 2. Water Extractable Sulfur in Ditch Sediments			
Sampling date:	06/18/14	07/16/14	07/16/14
	submerged	dry/field	dried and
Location	sediment	moist	rewetted
Upstream 100	5.5	28.0	22.8
Upstream 75	26.3	82.2	17.2
Upstream 50	25.1	91.3	36.0
Upstream 25	5.4	55.5	73.4
Curtain 1	4.4	72.4	395.1
Curtain 2	4.8	71.7	485.4
Curtain 3	3.8	81.0	267.3
Curtain 4	1.2	50.6	98.8
Downstream 25	4.2	64.3	103.3
Downstream 75	0.5	82.2	283.1
Downstream 125	0.5	77.8	275.9
Downstream 200	0.5	74.8	55.7

to moderate in upstream sediments and an order of magnitude higher in the ditch between curtain segments and the all along the downstream stretch.

In summary, under wet conditions in the ditch bottom, sulfur is in a reduced form, bound with iron as iron sulfide, and is relatively immobile. Under dry conditions in the ditch bottom, sulfur oxidizes to the sulfate form and is readily dissolved and transported downstream during the next flow event.

Development of a Conservation Practice Standard

In concert with the American Society of Agronomy By-product Gypsum Uses in Agriculture Community, Co-PI's Arthur Allen and Ray Bryant led the development of a conservation practice standard titled *"Amending Soil Properties with Gypsum Derived Products"*. Over 70 scientists from the international community participated in writing and reviewing the standard via a list serve. Participants on the writing team represent NRCS, ARS, EPA, Land Grant Universities, the coal combustion industry, and the agricultural community. A draft document was presented to the NRCS Agronomy Team for review and input in December, 2014. Currently, the writing team has responded to an initial round of proposed edits and comments made by the NRCS Agronomy Team and have submitted a revised draft for their review (See current draft in Appendix E).

Dissemination of Results

On May 23, 2012, a field day was conducted on Steve Cullen's farm *(See flyer and fact sheet in Appendix F)*. The purpose for installing gypsum curtains was explained and the method of installation was demonstrated. Approximately 30 people attended the field day. The audience included producers, Constellation Energy personnel, agency personnel from Natural Resources Conservation Service, Maryland Soil and Water Conservation District, MDE, MDA, scientists from several Land-Grant Institutions (UD, UMD, UMES), and graduate and undergraduate students.

Two subsurface imaging training workshops were conducted at the UMES Campus in 2014. Participants included 16 scientists, and three graduate students from Penn State, Univ. of Delaware, USDA-ARS, and Rutgers University (trainers). Field deployment of electrical resistivity imaging (ERI) instrumentation and computational training focused on groundwater and nutrient movement from field to ditch in the vicinity of gypsum curtains.

This project resulted in completion of a Master's degree by a student studying at the University of Maryland, College Park. The project provided research internship training for six undergraduate students at various stages of matriculation at the University of Maryland Eastern Shore.

Project data and results were presented at two local Maryland Waterkeepers Alliance meetings. Presentations were made at the meetings of the American Society of Agronomy and the Soil and Water Conservation Society. Co-PI's Ray Bryant and Arthur Allen served as Leaders of the American Society of Agronomy By-product Gypsum Uses in Agriculture Community in 2013 and 2014 respectively. They organized and presided over a joint symposium on the "Science behind a Conservation Practice Standard for Gypsum Soil Amendments" at the 2014 meetings of the American Society of Agronomy in Long Beach, CA. The session included 11 invited speakers and was attended by more than 200 scientists.

Conclusions and Recommendations

From a resource conservation perspective, surface application of gypsum is an effective and economical practice for protecting water quality by reducing dissolved P losses in runoff and in groundwater pathways. It can also ameliorate subsoil acidity, improve infiltration, and reduce pathogen losses. From an agronomic perspective, surface application of gypsum is a source of calcium and sulfur and can also be used to correct salinity/sodicity. Producers perceive an economic benefit in addition to the resource conservation benefits. We recommend formal adoption of the conservation practice standard for surface application of gypsum derived products.

Gypsum curtains are an effective edge-of-field technology for reducing dissolved P movement to drainage ditches via groundwater pathways. However, using gypsum in this fashion does not have the added benefits afforded by surface application. Although the effects are long lasting, the practice is considerably more expensive with costs more in line with land reclamation practices. Gypsum curtains should be reserved for extreme cases where P losses cannot be effectively controlled by surface application. Developing a separate practice standard for gypsum curtains should be considered. Gypsum curtains were excluded from the current draft standard because the practice requires special engineering criteria, such as trench depth, width, etc., which would have complicated development of a standard for surface application.

We also recommend considering a tandem approach of dissolved P abatement strategies. For example, use gypsum curtain and surface applications in tandem with various innovative biofilters, and other technologies to remove N, P and As (in high As areas). After all, at this point there are no *silver bullets*. However, cost must be considered to the producer and other communities involved.

Additional Outcomes

Anne Cowenhoven, Manager of Coal Combustion Products for Raven Energy, is very interested in building an agricultural market for FGD gypsum. We have assisted Anne by advising her in regard to obtaining product analyses and navigating State regulatory agencies. To date, Maryland Department of Agriculture has granted Raven Power a label for their FGD gypsum to be sold as an agricultural amendment in Maryland. Project PI's accompanied Anne and other Raven Power officials to a meeting with Martha Henson, Chief of Solid Waste Operation Division of the Maryland Department of the Environment, where they requested approval for beneficial use of FGD gypsum in agriculture (decision pending). The strongest justification for approval hinges on the experience gained in this project and the development of a draft NRCS Conservation Practice Standard for amending soils with gypsum derived products.

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APPENDIX A

Project Leaders Qualifications

VITAS

Arthur L. Allen, Ph.D.

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Education:

- Doctor of Philosophy 1971 - University of Illinois-Urbana, Major: Soil Chemistry
- Master of Science -1968, Oklahoma State University
- Bachelors of Science - 1966, University of Arkansas at Pine Bluff

Employment History

- July, 2000 to present - Associate Professor /Professor-1890 Associate Research Director - Director of the University's Geospatial Information Technology Program University of Maryland Eastern Shore
- January, 1996 -2000-Chairman, Associate Professor-Department of Agriculture & Associate Research Director - 1890 Programs – University of Maryland Eastern Shore. Director of the University's Geospatial Information Technology Program

Honors and Awards

- American Society of Agronomy, Fellow-2013
- Soil and Water Conservation Society, *Best Research Paper Awards for Impact and Quality* - 2010.
- 2011 Mid-Atlantic Regional Educational Institution and Federal Laboratory Partnership Award 2011
- University of Maryland *System-Wide* Board of Reagent's Award for Outstanding Faculty Service in Research. 2011
- USDA National Research Initiative Program's Project of Excellence Award. 2010

Selected funded projects:

1. Establishing a Living Marine Resources Cooperative Center. Funded by NOAA/Department of Commerce. Served as Core Grant writer with three others. Grant funded for $7.5 Million/5 years.
2. Managing Drainage Ditch Ecosystems to Minimize Nutrient Movement. USDA National Water Quality Initiative Program. Co-Investigator -UMCP- $530,679 -2003-2006.
3. Development of a Production and Planting Business for Submerged Aquatic Vegetation. $299,965. NOAA. Principal Investigator – 2003-2006.
4. An assessment of Drinking Water Quality Among Under-Served Families in Selected Counties on the Eastern Shore of Maryland and Delaware. USDA National Water Quality Initiative Program. $89,000. Investigator. 2002-2004.
5. An assessment of Drinking Water Quality Among Under-Served Families in Selected Counties on the Eastern Shore of Maryland and Delaware. USDA National Water Quality Initiative Program. $174,000. Principal Investigator 2005-2008.
6. Geo-spatial Information Technology Infrastructure Enhancement. USDA Capacity Building Grants Program. 2004- 2006 - $195,078.
8. Development of a Subsurface Application Technology for Dry Poultry Litter to Protect Air and

Water Quality. USDA Capacity Building Grants Program. $599, 880. 2010-2013. Principal Investigator.

9. Gypsum Curtains: Reducing soluble phosphorus losses from phosphorus-saturated soils on poultry operations. USDA-NRCS Conservation Innovation Grant. 2010. $1,999, 987 ($1-million match from Constellation Energy, Inc.) 2010-2013. Principal Investigator.
10. Watershed level examination of urea use as fertilizer, and the production of the biotoxin domoic acid. 2010. USDA Capacity Building Grants Program. 2010-2013. $499.968. Co-Investigator.

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2. Robert E. Vaughan, Brian A. Needelman, Peter J. A. Kleinman, and Arthur L. Allen. 2007. Spatial Variation of Soil Phosphorus within a Drainage Ditch Network. Journal of Environmental Quality 36: 1096-1104.
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8. Atalay A., S. Pao1, M. James, B. Whitehead and A. Allen. Drinking water assessment at underserved farms in Virginia's coastal plain. Journal of Environmental Monitoring & Restoration *4:54-65, 2008.*JEMREST 4:54-65, 2008.
9. Sharpley, Andrew N., Peter J.A. Kleinman, Philip Jordan, Lars Bergström, and Arthur L. Allen. 2009. Evaluating the Success of Phosphorus Management from Field to Watershed. J. Environ. Qual. 38:1981–1988 (2009).
10. Shigaki, F., P.J.A. Kleinman, J.P. Schmidt, A.N. Sharpley and A.L. Allen. 2008. Impact of dredging on phosphorus transport in agricultural drainage ditches of the Atlantic Coastal Plain. J. Amer. Water Res. Assoc. 44(6):1500-1511.

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Lou S. Saporito, and Thomas R. Way. Phosphorus runoff losses from subsurface-applied poultry litter on Coastal Plain soils. 2010. Journal of Environmental Quality.40: Pages 412-420. No.2

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16 Clinton D. Church, Peter J. A. Kleinman, Ray B. Bryant, Lou S. Saporito and Arthur L. Allen Occurrence of arsenic and phosphorus in ditch flow from litter-1 amended soils and barn areas. Journal of Environmental Quality 39: 2080- 2088. 2010

17 Daniel H. Pote, Thomas R. Way, Peter J. A. Kleinman, Philip A. Moored, John J. Meisinger, Karamat R. Sistanif, Louis S. Saporito, Arthur L. Allen, and Gary W. Feyereisen. 2010. Subsurface Application of Poultry Litter in Pasture and No-Till Soils. J. Environ. Quality. 40: Pages 402-411.

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**First authors in italics are graduate students supervised by A. Allen.*

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1. Peter Kleinman, Arthur Allen, and Brian Needelman. 2010. The role of drainage ditches in nutrient transfers from heavily manured fields of the Delmarva Peninsula. In: Moore, M. T., Kröger R., editors. Agricultural Drainage Ditches: Mitigation Wetlands for the 21st Century. Kerala, India: Research Signpost. p. 107-124.
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2. Arthur Allen and Peter Kleinman. 2008. Partnering over Agriculture and Water Quality in the Chesapeake Bay Watershed. 2008. USDA- CSRES Project Directors Conference. Beltsville, MD.
3. Arthur L. Allen, Peter Kleinman, Tracie Earl, and Fawzy Hashem. 2008. Exposing high school scholars to geospatial information technologies and water quality management. USDA - CSRES Project Directors Conference. Beltsville, MD.
4. David Ruppert, Brian Needelman, Peter Kleinman, Martin Rabenhors, Bahram Momen, and Arthur Allen. P Flux in Ditch Soil Mesocosms: The Effects of Pedologic and Hydraulic Treatments. International. October 5-9. Annual Meeting of the SSSA, Houston, TX. 2008.
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EDUCATION

Ph.D., Purdue University, Pedology, 1981

M.S., Texas Tech University, Soil Science, 1977 B.S., Texas Tech University, Soil Science, 1973

EMPLOYMENT

USDA – ARS, Supervisory Soil Scientist, 2001-present Cornell University, Professor, 1999-2001

Cornell University, Associate Professor, 1987-1997

Cornell University, Assistant Professor, 1981-1987

HONORS AND AWARDS

American Society of Agronomy, Fellow	
Outstanding (7), Superior (4) Performance Awards, USDA-ARS	2002-2012
Certificate of Appreciation, Equal Employment and Civil Rights, USDA-ARS	2005
National Honor Award, Soil Conservation Society of America	1987
Special Award for Student Activities, Soil Conservation Society of America	1983
Outstanding Teacher Award, Purdue University College of Agriculture	1981

INTERNATIONAL EXPERIENCE

- Member of faculty instruction team for Cornell graduate course, Agriculture in the Developing Nations: Mexico, Costa Rica, Honduras
- Member of Cornell faculty team conducting research on National Park land preservation: Dominican Republic, Guatemala
- Invited consultant on Soil Taxonomy and soil survey: Dominica, Venezuela, Panama, Hungary, The Netherlands, Lithuania, Latvia, Estonia, China

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4. Kleinman, P., R. Bryant, L. Saporito, D. Beegle, K. Saacke Blunk, et.al. 2012. Managing manure for sustainable livestock production in the Chesapeake Bay Watershed. J. Soil Water Cons. 67:54-61. doi:10.2489/jswc.67.2.54A

5. Jhu, Q., J.P. Schmidt, and R.B. Bryant. 2012. Hot moments and hot spots of nutrient losses from a mixed land use watershed. Journal of Hydrology. 414:393-404.

6. Jhu, Q., J.P. Schmidt, A.R. Buda, R.B. Bryant, and G.J. Folmar. 2011. Nitrogen loss from a mixed land use watershed as influenced by hydrology and seasons. Journal of Hydrology. 405:307-415.

7. **Bryant, R. B.**, T. L. Veith, G. W. Feyereisen, A. R. Buda, C. D. Church, G. J. Folmar, J. P. Schmidt, C. J. Dell, and P. J. A. Kleinman. 2011. U.S. Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Physiography and history, Water Resour. Res., 47, W08701, doi:10.1029/2010WR010056.

8. Rotz, C.A., K.J. Soder, R.H. Skinner, C.J. Dell, P.J. Kleinman, J.P. Schmidt, and **R.B. Bryant.** 2009. Grazing can reduce the environmental impact of dairy production systems. Online. Forage and Grazinglands doi:10. 1094/FG-2009-0916-01-RS.

9. **Bryant, R.B.**, T.L. Veith, P.J. Kleinman, and W.J. Gburek. 2008. Cannonsville Reservoir and Town Brook Watersheds: Documenting conservation efforts to protect New York City's drinking water. Journal of Soil and Water Conservation. (accepted 02/03/2008).

10. *Penn, C.J.*, **R.B. Bryant**, P.J. Kleinman, and A.L. Allen. 2007. Removing dissolved phosphorus from drainage ditch water with phosphorus sorbing materials. Journal of Soil and water Conservation. 62:269-276.

11. Kleinman, P.J., A.L. Allen, B.A. Needelman, A.W. Sharpley, P.A. Vadas, L.S. Saporito, G.J. Folmar, and **R.B. Bryant.** 2007. Dynamics of phosphorus transfers from heavily manured Coastal Plain soil to drainage ditches. Journal of Soil and Water Conservation. 62:225-234.

12. *Penn, C. J.** and **R.B. Bryant,** 2006. Application of phosphorus sorbing materials to streamside cattle loafing areas. Journal of Soil and Water Conservation. 61:303-310.

13. *Kogelmann, W. J.,* **R. B. Bryant,** H.S. Lin, D.B. Beegle, and J.L. Weld. 2006. Local assessments of the impacts of phosphorus index implementation in Pennsylvania. J. Soil Water Conservation 61:20-30.

14. **Bryant, R. B.**, W.J. Gburek, T.L. Veith, and W.D. Hively. 2006. Perspectives on the potential for hydropedology to improve watershed modeling of phosphorus loss. Geoderma 131 (3- 4):299-307.

15. Baveye, P., A.R. Jacobson, S.E. Allaire, J.P. Tandarich, and **R. B. Bryant.** 2006. Whither goes soil science in the US and Canada? Survey results and analysis. Soil Science 171: 501- 518.

16. *Hively, W. D.,* **R. B. Bryant,** and T.J. Fahey. 2005. Phosphorus concentrations in runoff from diverse locations on a New York dairy farm. J. Env. Qual. 34:1224-1233.

17. *Srinivasan, M.S.*, **R.B. Bryant,** M.P. Callahan, and J.L. Weld. 2005. Manure Management and Nutrient Loss under Winter Conditions: A Literature Review. Journal of Soil and Water Conservation 61:200-209.

18. *Kogelmann, W. J.,* H.S. Lin, **R. B. Bryant,** D.B. Beegle, A.M. Wolf, and G.W. Petersen. 2004.

19. A statewide assessment of the impacts of phosphorus index implementation in Pennsylvania. J. Soil Water Conservation 59:9-18.

20. *Giasson, E.,* **R. B. Bryant,** and N.L. Bills. 2003. Optimization of phosphorus index and costs of manure management on a New York dairy farm. Agronomy J. 95:987-993.

21. *Mikhailova, E. A.,* **R. B. Bryant,** I.I. Vassenev, S.J. Schwager, and C.J. Post. 2000. Cultivation effects on soil carbon and nitrogen contents at depth in the Russian Chernozem. Soil Sci. Soc. Am. J. 64:738-745.

* *First authors in italics are graduate students or postdocs supervised by Bryant.*

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EDUCATION

Ph.D., Cornell University, Soil Science, 1999

B.A., Cornell University, Biology and Society, 1989

EMPLOYMENT

USDA-ARS, Research Soil Scientist, 1999-present

Penn State University, Dept. Crop and Soil Sci., Adj. Asst. Professor, 2002-present

HONORS AND AWARDS

1. American Society of Agronomy, Fellow
2. Soil and Water Conservation Society, *Best Research Paper Awards for Impact and Quality* 2000-2006 and 2007-2010.
3. U.S. Dept. of Agriculture, *Technology Transfer Award, 2003.* Awarded to Phosphorus Index Research Group.
4. Soil Science Society of America, Soil and Water Conservation Division (S-6), *Outstanding Young Scientist Award,* 2002.

SELECT RECENT GRANTS

1. Chesapeake Stewardship Fund, Innovative Nutrient and Sediment Reduction Grant ($785,000). Co-principal investigator. New subsurface applicator for dry poultry and dairy manures, 2009.
2. NOAA, Cooperative Institute for Coastal and Estuarine Environmental Technology ($74,000), *Principal investigator*. Direct incorporation of poultry litter into no-till soils to minimize nutrient runoff to Chesapeake Bay, 2006.
3. USDA-EQIP, Conservation Innovation Grant ($190,000), *Co-principal investigator*. Improved manure injection technologies for water and air quality protection, 2005.
4. Pennsylvania Department of Agriculture, research grant ($114,000), *Co-principal investigator*. Effect of manure injection technologies on water and air quality, 2005.

SELECT PEER REVIEWED PUBLICATIONS

1. *Kibet, L.C.*, A.L. Allen, C. Church, **P.J.A. Kleinman**, G.W. Feyereisen, L.S. Saporito, F. Hashem and T.R. Way. 2012. Transport of dissolved trace elements in surface runoff and leachate from a Coastal Plain soil after poultry litter application. (Accepted for publication in J. Soil Water Conserv.).
2. Buda, A.R., **P.J.A. Kleinman**, R.B. Bryant, G.W. Feyereisen, D.A. Miller, P.G. Knight, P.J. Drohan. 2012. Forecasting runoff from Pennsylvania landscapes. (Accepted for publication in J. Soil Water Conserv.).
3. Smith, B.D., F.M. Hashem, P. Millner, A.L. Allen, **P. Kleinman**, R. Bryant, L.E. Marsh, and C.P. Cotton. 2012. Microbial transport in runoff from soils amended with different manures. (Accepted for publication in J. Environ. Qual.)

4. Bryant, R.B., A.R. Buda, **P.J.A. Kleinman**, C.D. Church, L.S. Saporito, G.J. Folmar, S. Bose, and A.L. Allen. 2012. Using flue gas desulfurization gypsum to remove dissolved phosphorus from agricultural drainage waters. J. Environ. Qual. 41: 664-671.
5. **Kleinman, P.**, K. Saacke Blunk, R. Bryant, L. Saporito, D. Beegle, K. Czymmek, Q. Ketterings, T. Sims, J. Shortle, J. McGrath, F. Coale, M. Dubin, D. Dostie, R. Maguire, R. Meinen, A. Allen, K. O'Neill, L. Garber, M. Davis, B. Clark, K. Sellner, and M. Smith. 2012. Managing manure for sustainable livestock production in the Chesapeake Bay Watershed. J. Soil and Water Conserv. 67: 54A-61A.
6. Pote, D.H., T.R. Way, **P.J. Kleinman**, P.A. Moore, Jr. 2012. Subsurface application of dry poultry litter: Impacts on common bermudagrass and other no-till crops. J. Sustainable Forestry. 4: 55-62.
7. Dell, C.J., **P.J.A. Kleinman**, J.P. Schmidt and D.B. Beegle. 2012. Low disturbance manure incorporation effects on ammonia and nitrate loss. J. Environ. Qual. 41: 928-937.
8. Maguire, R.O., **P.J.A. Kleinman**, C. Dell, D.B. Beegle, R.C. Brandt, J.M. McGrath and Q.M. Ketterings. 2011. Manure management in reduced tillage and grassland systems: A review. J. Environ. Qual. 40: 292-301.
9. McDowell, R.W. and **P.J.A. Kleinman**. 2011. Efficiency of phosphorus cycling in different grassland systems. P. 108-119. In: G. Lemaire, J. Hodgson, and A. Chabbi (eds.), Grassland Productivity and Ecosystem Services. CABI Publishing, Oxfordshire, UK. (Book Chapter)
10. Pote, D.H., T.R. Way, **P.J.A. Kleinman**, P.A. Moore, J.J. Meisinger, K.R. Sistani, L.S. Saporito, A.L. Allen, and G.W. Feyereisen. 2011. Subsurface application of poultry litter in pasture and no-till soils. J. Environ. Qual. 40: 402-411.
11. Brandt, R.C., H.A. Elliott, M.A.A. Adviento-Borbe, E.F. Wheeler, **P.J.A. Kleinman**, and D.B. Beegle. 2011. Influence of manure application method on odor emissions. J. Environ. Qual. 40: 431-437.
12. Kibet, L.C., A.L. Allen, **P.J.A. Kleinman**, G.W. Feyereisen, C.D. Church, L.S. Saporito and T.R. Way. 2011. Phosphorus losses in surface runoff from a no-till Coastal Plain soil with surface and subsurface applied poultry litter. J. Environ. Qual. 40: 412-420.
13. Rotz, C.A., **P.J.A. Kleinman**, C.J. Dell, T.L. Veith and D.B. Beegle. 2011. Environmental and economic comparisons of manure application methods in farming systems. J. Environ. Qual. 40: 438-448.
14. Maguire, R.O., **P.J.A. Kleinman**, C. Dell, D.B. Beegle, R.C. Brandt, J.M. McGrath and Q.M. Ketterings. 2011. Manure management in reduced tillage and grassland systems: A review. J. Environ. Qual. 40: 292-301.
15. Johnson, K.N., A.L. Allen, **P.J.A. Kleinman**, F.M Hashem, A.N. Sharpley, and W.L. Stout. 2011. Effect of coal combustion byproducts on phosphorus runoff from a coastal plain soil. Commun. Soil Sci. Plan Anal. 42: 778-789.
16. Strock, J., **P. Kleinman**, K. King and J.A. Delgado. 2010. Drainage water management for water quality protection. J. Soil and Water Conserv. 65: 131A-136A.
17. Tao, L., S. Wen-Chong, W. Ling-Qing, **P.J.A. Kleinman** and C.A.O. Hong-Ying. 2010. Interactions between exogenous rare-earth elements and phosphorus leaching in packed soil columns. Pedosphere 20: 616-622.
18. Church, C.D., **P.J.A. Kleinman**, R.B. Bryant, L.S. Saporito and A.L. Allen. 2010. Occurrence of arsenic and phosphorus in ditch flow from litter-amended soils and barn areas. J. Environ. Qual. 39: 2080-2088.
19. Feyereisen, G.W., **P.J.A. Kleinman**, G.J. Folmar, L.S. Saporito, C.D Church, T.R. Way, and A.L Allen. 2010. Effect of direct incorporation of poultry litter on phosphorus leaching from Coastal Plain soils. J. Soil Water Conserv. 65: 243-251.

20. Verbree, D.A., S.W. Duiker, and **P.J.A. Kleinman**. 2010. Runoff losses of sediment and phosphorus from no-till and cultivated soils receiving dairy manure. J. Environ. Qual. 39: 1762-1770.
21. Henry, A., N.F. Chavez, **P.J.A. Kleinman** and J.P Lynch. 2010. Will nutrient-efficient genotypes mine the soil? Effects of genetic differences in root architecture in common bean (*Phaseolus vulgaris* L.) on soil phosphorus depletion in a low-input agro-ecosystem in Central America. Field Crops Res. 115: 67-78.
22. Buda, A.R., C. Church, **P.J.A. Kleinman**, L.S. Saporito, B.G. Moyer, and T. Liang. 2010. Using rare earth elements to control phosphorus and track manure in runoff. J. Environ. Qual. 39: 1028-1035.
23. **Kleinman, P.**, A. Allen and *B. Needelman*. 2010. The role of drainage ditches in nutrient transfers from heavily manured fields of the Delmarva Peninsula. p. 106-123. In Moore, M.T. and R. Kroger (eds.), Agricultural Drainage Ditches: Mitigation Wetlands for the 21st Century. Research Signpost Press, Kerala, India. (Book Chapter)
24. Dell, C.J., **P.J.A. Kleinman**, T.L. Veith, and R.O. Maguire. 2009. Implementation and monitoring measures to reduce agricultural impacts on water quality: U.S. Experience. Tearman (Irish Journal of Agi-Environmental Research) 7: 103-114.
25. **Kleinman, P.J.A.**, A.N. Sharpley, L.S. Saporito, A.R. Buda and R.B. Bryant. 2009. Application of manure to no-till soils: Phosphorus losses by sub-surface and surface pathways. Nutrient Cycl. Agroecos. 84: 215-227.
26. Buda, A.R., **P.J.A. Kleinman**, M.S. Srinivasan, R.B. Bryant, and G.W. Feyereisen. 2009. Effects of hydrology and field management on phosphorus transport in surface runoff. J. Environ. Qual. 38: 2273-2284.
27. Buda, A.R., **P.J.A. Kleinman**, M.S. Srinivasan, R.B. Bryant, and G.W. Feyereisen. 2009. Factors influencing surface runoff generation from two agricultural hillslopes in central Pennsylvania. Hydrol. Process. 23: 1295-1312.
28. Rotz, C.A., K.J. Soder, R.H. Skinner, C.J. Dell, **P.J. Kleinman**, J.P. Schmidt and R.B. Bryant. 2009. Grazing can reduce the environmental impact of dairy production systems. Forage and Grazinglands, Sept.: http://www.plantmanagementnetwork.org/sub/fg/research/2009/impact/
29. Sharpley, A.N., **P.J.A. Kleinman**, P. Jordan, L. Bergström, and A.L. Allen. 2009. Evaluating the success of phosphorus management from field to watershed. J. Environ. Qual. 38: 1981-1988.
30. Shigaki, F., J.P. Schmidt, **P.J.A. Kleinman**, A.N. Sharpley, and A.L. Allen. 2009. Nitrogen fate in drainage ditches of the Coastal Plain after dredging. J. Environ. Qual. 38: 2449-2457.

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EDUCATION

Ph.D., 2007 Forest Hydrology, Pennsylvania State University, University Park, PA

M.S., 2000 Forest Resources with Option in Watershed Stewardship, Pennsylvania State University, University Park, PA

B.S., 1998 Environmental Science, Susquehanna University, Selinsgrove, PA

EMPLOYMENT

2009 – Present Research Hydrologist, USDA Agricultural Research Service, Pasture Systems and Watershed Management Research Unit, University Park, PA

2007 – 2009 Postdoctoral Research Hydrologist, USDA-ARS / Canaan Valley Institute, University Park, PA

HONORS AND AWARDS

- 2011 Inspiring Young Scientist Award, American Society of Agronomy, Environmental Quality Section 2012 Early Career Research Scientist of the Year Award, USDA-ARS, North Atlantic Area
- 2012 Young Scientist Award, Soil Science Society of America, Soil and Water Conservation Division

SELECT RECENT GRANTS

1. USDA, NIFA-AFRI ($488,000). Co-principal investigator. Developing a web-based forecasting tool for nutrient management, 2011.
2. USDA, Capacity Building Grant ($499,938). Co-principal investigator. Watershed level examination of urea use as fertilizer and the production of the biotoxin domoic acid, 2010.
3. USDA, Conservation Innovation Grant ($999,987), Co-principal investigator. Gypsum curtains: reducing soluble phosphorus losses from P-saturated soils on poultry operations, 2010.
4. USDA, Soil Survey ($185,000). Co-principal investigator. Enhancing soil survey information to identify environmentally sensitive wet landscapes (Pennsylvania), 2010.

PEER-REVIEWED PUBLICATIONS

1. **Buda, A.R.** 2013. Surface runoff generation and forms of overland flow. *In*: R. Marston and M. Stoffel (Eds.), Treatise on Geomorphology: Mountain and Hillslope Geomorphology. Elsevier. *In Press*.

2. **Buda, A.R.**, P.J.A. Kleinman, G.W. Feyereisen, D.A. Miller, P.G. Knight, P.J. Drohan, and R.B. Bryant. 2013. Forecasting runoff from Pennsylvania landscapes. *J. Soil Water Conserv*. *In press.*

3. Zhang, Y., M.S. Moran, M.A. Nearing, G. Campos, A. Huete, **A.R. Buda**, D.D. Bosch, S.A. Gunter, S.G. Kitchen, W.H. McNab, J.A. Morgan, M.P. McLaren, D.S. Montoya, D.C. Peters, and P.J. Starks. 2013. Extreme precipitation patterns reduced terrestrial ecosystem production across biomes. *J. Geophys. Res.* DOI:10.1029/2012JG002136.

4. Ponce, G., Y. Zhang, T.E. Huxman, M. McClaren, M.S. Moran, C. Bresloff, A. Huete, D. Eamus, D.D. Bosch, **A.R. Buda**, S.A. Gunter, S.G. Kitchen, W.H. McNab, J.A. Morgan, D.C. Peters, E.J. Sadler,

5. M.S. Seyfried, P.J. Starks, D. Montoya, T.H. Scalley. 2013. Loss of ecosystem resilience under large-scale altered hydroclimatic condition. *Nature*. DOI:10.1038/nature11836.

6. **Buda, A.R.**, G.F. Koopmans, R.B. Bryant, and W.J. Chardon. 2012. Emerging technologies for removing nonpoint phosphorus from surface water and groundwater: introduction. *J. Environ. Qual*. 41: 621-627. DOI:10.2134/jeq2012.0080.

7. Bryant, R.B, **A.R. Buda**, P.J.A. Kleinman, C.D. Church, L.S. Saporito, G.J. Folmar, S. Bose, A.L. Allen.

8. 2012. Using flue-gas desulfurization gypsum to remove dissolved phosphorus from agricultural drainage waters. *J. Environ. Qual*. 41: 664-671. DOI:10.2134/jeq2011.0294.

9. Sharpley, A.N., P.J.A. Kleinman, D.N. Flaten, and **A.R. Buda**. 2011. Critical source area management of agricultural phosphorus: experiences, challenges, and opportunities. *Water Sci. Technol*. 64(4): 945-952. DOI: 10.2166/wst.2011.712.

10. Kleinman, P.J.A., A.N. Sharpley, R.W. McDowell, D. Flaten, **A.R. Buda**, L. Tao, L. Bergstrom, and Q. Zhu. 2011. Managing agricultural phosphorus for water quality protection: principles for progress. *Plant Soil*. 349(1-2): 169-182. DOI: 10.1007/s11104-011-0832-9.

11. Bryant, R.B., T.L. Veith, G.W. Feyereisen, **A.R. Buda**, C.D. Church, G.J. Folmar, J.P. Schmidt, C.J. Dell, and P.J.A. Kleinman. 2011. US Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Physiography and history. *Water Resour. Res*. DOI: 10.1029/2010WR010056.

12. **Buda, A.R.**, G.W. Feyereisen, T.L. Veith, G.J. Folmar, R.B. Bryant, C.D. Church, J.P Schmidt, C.J. Dell, and P.J.A. Kleinman. 2011. US Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Long-term stream discharge database. *Water Resour. Res*. DOI: 10.1029/2010WR010059.

13. **Buda, A.R.**, T.L. Veith, G.J. Folmar, G.W. Feyereisen, R.B. Bryant, C.D. Church, J.P Schmidt, C.J. Dell, and P.J.A. Kleinman. 2011. US Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Long-term precipitation database. *Water Resour. Res*. DOI: 10.1029/2010WR010058.

14. Church, C.D., T.L. Veith, G.J. Folmar, **A.R. Buda**, G.W. Feyereisen, R.B. Bryant, J.P Schmidt, C.J. Dell, and P.J.A. Kleinman. 2011. US Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Long-term water quality database. *Water Resour. Res*. DOI: 10.1029/2010WR010060.

15. Zhu, Q., J.P. Schmidt, **A.R. Buda**, R.B. Bryant, and G.J. Folmar. 2011. Nitrogen loss from a mixed land use watershed as influenced by hydrology and seasons. *J. Hydrol*. 405(3-4): 307-315. DOI: 10.1016/j.jhydrol.2011.05.028.

16. Kleinman, P.J.A., A.N. Sharpley, **A.R. Buda**, R.W. McDowell, and A.L. Allen. 2011. Soil controls of phosphorus in runoff: management barriers and opportunities. *Can. J. Soil Sci*. 91(3): 329-338. DOI: 10.4141/CJSS09106.

17. **Buda, A.R.**, C. Church, P.J.A. Kleinman, L.S. Saporito, B.G. Moyer, and L. Tao. 2010. Using rare earth elements to control phosphorus and track manure in runoff. *J.Environ. Qual*. 39: 1028-1035. DOI: 10.2134/jeq2009.0359.

18. **Buda, A.R.**, P.J.A. Kleinman, M.S. Srinivasan, R.B. Bryant, and G.W. Feyereisen. 2009. Effects of hydrology and field management on phosphorus transport in surface runoff. *J.Environ. Qual*. 38: 2273- 2284. DOI: 10.2134/jeq2008.0501.

19. **Buda, A.R.** and D.R. DeWalle. 2009. Dynamics of stream nitrate sources and flow pathways during stormflows on urban, forest, and agricultural watersheds in central Pennsylvania, USA. *Hydrol. Process*. 23: 3292-3305. DOI: 10.1002/hyp.7423.

20. **Buda, A.R.** and D.R. DeWalle. 2009. Using atmospheric chemistry and storm track information to explain the variation of nitrate stable isotopes in precipitation at a site in central Pennsylvania, USA. *Atmos.*

21. *Environ*. 43: 4453-4464. DOI: 10.1016/j.atmosenv.2009.06.027.

22. **Buda, A.R.**, P.J.A. Kleinman, M.S. Srinivasan, R.B. Bryant, and G.W. Feyereisen. 2009. Factors influencing surface runoff generation from two agricultural hillslopes in central Pennsylvania. *Hydrol. Process*. 23: 1295-1312. DOI: 10.1002/hyp.7237.

23. Kleinman, P.J.A., A.N. Sharpley, L.S. Saporito, **A.R. Buda**, and R.B. Bryant. 2009. Application of manure to no-till soils: phosphorus losses by subsurface and surface pathways. *Nutr. Cycl. Agroecosys*. 84(3): 215-227. DOI: 10.1007/s10705-008-9238-3.

24. DeWalle, D.R., **A.R. Buda**, J.A. Eismeier, W.E. Sharpe, B.R. Swistock, P.L. Craig, and M.A. O'Driscoll. 2005. Nitrogen cycling on five headwater forested catchments in Mid-Appalachians of Pennsylvania. *IN*: Dynamics and Biogeochemistry of River Corridors and Wetlands (Proceedings of symposium S4 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005). IAHS Publ. 294, 2005. http://www.cig.ensmp.fr/~iahs/redbooks/294.htm

25. DeWalle, D.R., **A.R. Buda**, and A. Fisher. 2003. Extreme weather and forest management in the Mid- Atlantic region of the United States. *North. J. Appl. For*. 20(2): 61-70.

26. **Buda, A.R.** and D.R. DeWalle. 2002. Potential effects of changes in precipitation and temperature on wet deposition in central Pennsylvania. *Atmos. Environ*. 36: 3767-3778. DOI: 10.1016/S1352-2310(02)00223-6.

27. McKenney-Easterling, M., D.R. DeWalle, L.R. Iverson, A.M. Prasad, and **A.R. Buda**. 2000. The potential effects of climate change and variability on forests and forestry in the Mid-Atlantic Region. *Clim. Res*. 14: 195-206. DOI: 10.3354/cr014195.

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Education:

- Ph.D. Agricultural Engineering, Texas A&M, 1987.
- M.S. Agricultural Engineering, University of Maryland, 1981.
- B.S. Agricultural Engineering, University of Maryland, 1976.

Professional Service:

Professional Society Memberships

- American Society of Agricultural and Biological Engineers (ASABE), 1987-present
- Washington DC/Maryland section, ASAE
- Association of Ground Water Scientists and Engineers

Selected Grants:

1. Quantifying Nitrogen Fate from Hybrid Poplar Production on Biosolids Incorporated into Deep Rows. G.K. Felton, J.S. Kays, E. Flamino. Sponsor: USDA [McIntire - Stennis Funds Funding: $60,000, Duration: January 2003 - December 2007, Role: P.I.
2. Mid-Atlantic Regional Water Quality Coordination Project. T.W. Simpson, G.K. Felton. Sponsor: USDA - CSREES , Funding: $1,294,500 ,Duration: Oct. 2002 - Sept. 2004, Role: Co-P.I.
3. Determination of Optimum Tree Density and Biosolid Application Rate and the Effect on Water Quality and Tree Growth Using the Deep Row Biosolids Incorporation Method. Kays, J.S., G.K. Felton, D. Johnson, E. Flamino. Sponsor: Washington Suburban Sanitary Commission Funding: $265,262, Duration: January 2002 - December 2004, Role: Co-Investigator ,
4. Nutrient Fate and Transport Associated with Poultry Litter Stock Piles G.K. Felton, L.E. Carr; U. MD. E. Collins and B. Ross; VPI&SU. Sponsor: US EPA - Chesapeake Bay Program Funding: $94,722, Duration: October 2000 - September 2002, Role: Principal Investigator ,
5. Immobilization of Soluble Phosphorus in Animal Waste with SWAN-Gypsum and Iron Oxide Filter Cake Co-Products. Felton, G.K., K.J. Hughes, and L.J. Ottmar Sponsor: Maryland Industrial Partnerships and Millennium Inorganic Chemicals, Inc., Funding: $309,676 ,Duration: February 2000 - January 2002, Role: Principal Investigator ,
6. Phosphorus Removal from Animal Waste with SWAN-Gypsum. G.K. Felton, K.J. Hughes Sponsor: Millenium Inorganic Chemicals Inc. Funding: $175,000 , Duration: 1999 - 2000 Role: Principal Investigator ,
7. Baltimore Sun Partnership to Raise Environmental Awareness of One Million Citizens. Felton, G.K. Sponsor: USDA/CSREES Water Quality Program , Funding: $40,000, Duration: June 1999 - May 2000, Role: Principal Investigator ,

8. Urban Nutrient Management in Maryland. Felton, G.K., and T. Miller. Sponsor: USDA/CSREES Water Quality Program , Funding: $60,000 , Duration: June 1999 - May 2001, Role: Principal Investigator , and

9. Environmental Benefits and Costs of a Voluntary Riparian Forest Buffer Program in the Chesapeake Bay Watershed. Hardie, I., A.H. Baldwin, G.K. Felton, L.L. Lynch, E. Russek-Cohen, R.L. Tjaden. Sponsor: USDA/CSREES Fund for Rural America , Funding: $205,000, Duration: 1999 - 2000 , Role: Co-Investigator

Selected Publications:

1. Felix, E., D.R. Tilley, **G.K. Felton**, E. Flamino. 2008. Biomass production of hybrid poplar (Populus spp.) grown on municipal biosolids. Ecological Engineering. 33 (2008):8-14.

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3. L.S. Barker, **Gary K. Felton**, E. Russek-Cohen. 2006. Use of Maryland Biological Stream Survey data to determine effects of agricultural riparian buffers on measures of biological stream health. Submitted to Environmental Monitoring and Assessment. (2006) 117:1-19.

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APPENDIX B

MDE Correspondence

MARYLAND DEPARTMENT OF THE ENVIRONMENT - MDE

1800 Washington Boulevard, Suite 610 • Baltimore MD 21230-1719
410-537-3000 • 1-800-633-6101• www.mde.state.md.us

Martin O'Malley Robert M. Summers, Ph.D. Governor Secretary

Anthony G. Brown Kathy M. Kinsey Lieutenant Governor Deputy Secretary

August 15, 2011

Dr. Ray B. Bryant
Research Soil Scientist
Pasture Systems & Watershed
Management Research Unit
Building 3702, Curtin Road
University Park PA 16802-3702

Dear Dr. Bryant:

The Maryland Department of the Environment (MDE), Solid Waste Program (SWP), has reviewed your proposal to conduct a research project using Flue Gas Desulfurization (FGD) gypsum to remove soluble phosphorus and arsenic from agricultural drainage waters. You have stated that some of this research project would be conducted on three farms owned by Mr. Steven Cullen near Crisfield in Somerset County.

The research project involves the installation of FGD gypsum-filled trenches (gypsum curtains) parallel to open agricultural drainage ditches to precipitate soluble phosphorus, as well as shallow land incorporation of the FGD gypsum to increase the infiltration rate of the surface horizon, thereby minimizing runoff and enhancing downward leaching and lateral groundwater movement to the ditch. The FGD gypsum is to be brought to the farm sites by Constellation Power Generation in covered trucks, and then placed on tarps and covered by tarps to prevent loss in rainfall generated runoff until the material is placed in the trenches.

The SWP supports the beneficial use of coal combustion byproducts (CCBs) in a safe and environmentally friendly
manner, and has no objections to this research project as proposed, so long as the requirements governing the transportation and storage of CCBs found in Code of Maryland Regulations 26.04.10 are adhered to. It is our understanding that you will also be in contact with MDE's Water Management Administration to determine whether permits will be required from them for this research project.

If you have any questions regarding this letter, please contact Ms. Martha Hynson, Chief of the Solid Waste Operations Division at 410-53 7-3318.

Si~/k~

Edward M. Dexter, Administrator Solid Waste Program

EMD: MH: mh

cc: Mr. Horacio Tablada Ms. Martha Hynson ~Recycled Paper www. mde.state.md.us TTY Users 1-800-735-2258 Via Maryland Relay Service

APPENDIX C

FGD Gypsum Analyses

(Appended as separate pdf file)

Appendix_C_69-3A75-10-126.pdf

APPENDIX D

Farm Maps

(Appended as separate pdf file)

Appendix_D_69-3A75-10-126.pdf

APPENDIX E

Conservation Practice Standard

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

AMENDING SOIL PROPERTIES WITH GYPSUM PRODUCTS

(Ac.)

CODE XXX

DEFINITION

Using gypsum (calcium sulfate dihydrate) derived products to change the physical and/or chemical properties of soil.

PURPOSE

- Improve soil physical/chemical properties and increase infiltration
- Improve surface water quality by reducing dissolved phosphorus concentrations in surface runoff. and subsurface drainage
- Ameliorate subsoil Al toxicity
- Improve water quality by reducing the potential for pathogens and other contaminants transport from areas of manure and biosolids application

CONDITIONS WHERE PRACTICE APPLIES

- This practice applies where land application of gypsum products will be used to alter the physical and/or chemical characteristics of soil to help achieve one of the above purposes, and
- To remediate sodic soils, use the conservation practice Salinity and Sodic Soil Management (Code 610)

CRITERIA

General Criteria Applicable To All Purposes

Validation of product. It is the responsibility of the amendment provider to furnish the following documentation to the producer:

- Chemical analysis of the product, which will include the calcium and sulfur content and content of heavy metals and other potential contaminants listed in Table 1.
- Concentrations of potential contaminants cannot exceed maximum allowable concentrations listed in Table 1. In addition, the radium-226 concentration in the gypsum derived product cannot exceed 10 picocuries per gram (pCi/g).
- Flue gas desulfurization (FGD) gypsum that is produced by forced-oxidation wet systems after the removal of fly ash is acceptable for these uses.
- The prescribed minimum application rates are based on a calcium sulfate dihydrate equivalency of 100%. Application rates for products that are less than 100% calcium sulfate dihydrate equivalence should be adjusted accordingly.

- Gypsum derived products must have a particle size less than 1/8 inch. Fluid application is acceptable.

Do not exceed annual application rates of 5 tons/acre for the purposes defined in this standard. Where needed according to use, a soil test no older than one year to plan the appropriate application rate of the gypsum products.

Additional criteria to improve soil physical/chemical properties and increase infiltration

- Use Table 2 to determine the application rate of gypsum products when slow infiltration and percolation due to poor aggregation is caused by an imbalance between calcium and magnesium.
- Gypsum may be applied to pastures anytime livestock are not present. Do not allow livestock re-entry until the gypsum products have been removed from the vegetation by rainfall/irrigation.

Additional Criteria to improve surface water quality by reducing dissolved phosphorus concentrations in surface runoff.

- **General Use on High P Soils** – Apply no less than 1 ton/acre broadcast on the soil surface when soil test phosphorus (STP) is greater than two times the "maximum optimum level" for crop production, or when the P Index rating for the field is ***HIGH*** or ***VERY HIGH***.
- **Manure Application** – Broadcast no less than 1 ton/acre of gypsum within 5 days after manure application or prior to the next runoff event, whichever occurs first. Mixing gypsum with manure prior to application is acceptable. Under anaerobic conditions, gypsum added to liquid manure storage facilities can result in dangerous levels of hydrogen sulfide emissions and mixing or agitation cannot be conducted indoors.

Additional Criteria to Ameliorate Subsoil Al Toxicity

- When exchangeable aluminum below a 12-inch soil depth is greater than 1.0 meq/100 mg soil, apply gypsum at a rate recommended by the Land Grant University (LGU) or ARS.

Additional Criteria to Reduce the Potential for Pathogen Transport

- Apply no less than 2 tons/acre of gypsum within 5 days after manure or biosolid application, or prior to the next runoff event after manure application, whichever occurs first.

CONSIDERATIONS

General Considerations

- Gypsum should not be applied in watersheds where sulfate additions are restricted.
- If soil pH is less than 5, the application of products with high sulfite content may be harmful to plants that are present at the time of application.
- Long-term use of gypsum or using rates higher than given in the criteria can have adverse impacts on soil or plant systems. This can include:
- Where gypsum derived products are alkaline due to impurities, raising the soil pH to a level that is detrimental to plant growth or nutrient balance.

- Creating a calcium imbalance with other mineral nutrients such as magnesium and potassium.

Additional Considerations for Improving Soil Physical/Chemical Properties and increasing infiltration

- There is some research that shows gypsum application can increase crop rooting depth, total root biomass, and nitrogen uptake.

Additional Considerations to improve surface water quality by reducing dissolved phosphorus concentrations in surface runoff

- Increasing the gypsum application rate beyond that set in Criteria will provide an additional decrease in dissolved phosphorus loss. However, the additional decrease at rates above 2 tons/acre is not proportional to the additional cost.

PLANS AND SPECIFICATIONS

Plans and specifications shall include the following information as a minimum:

- The source of the product, e. g., flue gas desulfurization, mined
- Purpose(s) for its use and the planned outcomes
- Chemical analysis of the amendment product
- Soil analyses that demonstrate the need for the amendment
- Application methodology, including rates, timing, sequence of application with other nutrient materials (i.e., manures, biosolids, fertilizers), mixing instructions when mixed with manure prior to field application
- Required soil and/or plant analyses after application to determine the effectiveness of the amendment as appropriate.

OPERATION AND MAINTENANCE

- Do not allow livestock access to stacked gypsum.
- Do not resume grazing until rainfall or irrigation has washed gypsum off of the vegetation.
- Do not apply gypsum after the soil test calcium level exceeds the maximum level established by the Land Grant University.

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Table 1. Screening values for elements in gypsum derived products for use as a soil amendment.

Element	Units	Screening Value for Gypsum Derived Products	
Ag	mg kg^{-1}	.	No limit required
Al	g kg^{-1}	.	No limit required
As	mg kg^{-1}	13.1	
B[†]	mg kg^{-1}	200.[†]	
Ba	mg kg^{-1}	1000.	
Be	mg kg^{-1}	2.5	
Ca	g kg^{-1}	.	Ca fertilizer; No limit required
Cd[‡]	mg kg^{-1}	1.0	
Co	mg kg^{-1}	20.	
Cr(III)	mg kg^{-1}	100.	
Cu	mg kg^{-1}	95.	
Fe	g kg^{-1}	.	No limit required
Hg	mg kg^{-1}	2.5	
Mg	g kg^{-1}	.	Mg fertilizer; No limit required
Mn	mg kg^{-1}	1500.	
Mo	mg kg^{-1}	10.	
Ni	mg kg^{-1}	100.	
Pb	mg kg^{-1}	30.	
S*	g kg^{-1}	220.	S fertilizer; *Limit access to ruminants
Sb	mg kg^{-1}	1.5	
Se	mg kg^{-1}	50.	
Sn	mg kg^{-1}	.	No limit required
Tl	mg kg^{-1}	1.0	
V	mg kg^{-1}	136.	
Zn	mg kg^{-1}	125.	

[†] Should not apply greater than 0.9 lb hot water soluble B/acre with gypsum amendment application rate.

* Prevent ruminant livestock from ingesting gypsum from storage piles; prevent grazing on amended pastures until one rainfall event to wash forage.

Table 2: Gypsum derived product application rate determination to improve soil physical/chemical properties and increase infiltration.

Cation exchange capacity (CEC) is an indirect indicator of clay and organic matter content of soil and is related to how adjustment is needed when certain cations are excessive or deficient. The saturation ranges in Table 2a represent optimal cation availability for good soil structure as well as plant and biological use.

Table 2a: Target ranges for base saturation of cations to improve soil chemical and physical properties.

Base Saturation	Balanced
Calcium	70 – 80%
Magnesium	10 – 13%
Potassium	2 – 5%
Hydrogen	1 – 10%

Of the cations listed, calcium and magnesium have the greatest impact on soil structure. Lower CEC soils that tend to be droughty would prefer calcium at the lower end of the range and magnesium to be at the higher end. Higher CEC soils tend to perform best with calcium at mid-to-hi range and magnesium at the lower end of the range. (NOTE: Amendment tables based on electrical conductivity for addressing saline and sodic soils are not addressed in this standard.)

Table 2b lists recommended annual application rates based on CEC. Multiple applications at the recommended rates will improve soil chemical and physical properties in a reasonable time without creating soil nutrient imbalances. Once the ratios shown in Table 2a are achieved, application rates can be reduced or stopped until soil test values indicate otherwise.

Table 2b: Gypsum application rates to improve soil chemical and physical properties.

CEC	Rate (ton/acre)*
<5	0.5
5 – 10	1
10 – 15	2
>15	4

Goal: Base saturation of Ca = 70% to 80%

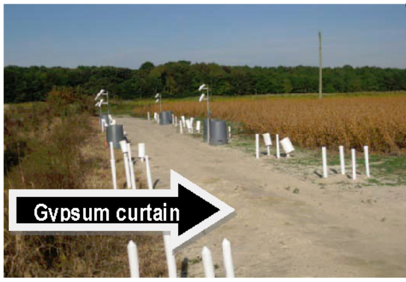
* Annual application rate in ton gypsum/acre

APPENDIX F

Field Day Flyer and Fact Sheet

University of Maryland Eastern Shore
USDA Agricultural Research Service

Field Day Announcement



"THE GYPSUM CURTAIN PROJECT"

Using Flue Gas Desulfurization (FGD) Gypsum
To Minimize Soluble Phosphorus Loss from Soils

The gypsum curtain project is a partnership effort among the University of Maryland Eastern Shore, USDA Agricultural Research Service, Exelon Corporation-Constellation Energy (ECCE), and The University of Maryland. The project is funded by a USDA Natural Resources Conservation Innovation Grant at $1 million with $1 million in matching from ECCE in the form of FGD gypsum delivered to the farm sites.

Project objectives:

1. Implement and demonstrate the effectiveness of gypsum curtains for reducing soluble phosphorus (P) loss from farms in Somerset County, a key poultry producing region on the Eastern Shore of Maryland.
   a. demonstrate effectiveness at the farm scale,
   b. demonstrate effectiveness across different soil types in the region,
   c. evaluate potential adverse environmental impacts
2. obtain producers' evaluations of this practice in the context of whole farm operations,
3. adjust the practice to address producers' concerns if necessary, and
4. Work in concert with NRCS personnel and others to develop standards for this practice.

WHO: Local Producers, Project Leaders, Industry Partners, Local, State and Federal Agency Representatives

WHAT: Field Demonstration

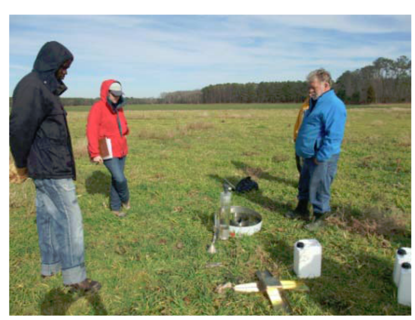
WHEN: Wednesday, May 23, 2012
11:00 A.M. to 1:00 P.M.

WHERE: Steve Cullen Home Farm
Box Iron Road, Crisfield, MD

DETAILS:

- **Gypsum Curtain installation will be demonstrated (weather permitting)**
- **Monitoring plan and instrumentation will be explained**
- **Research data will be presented.**
- **Lunch will be provided (Linton's Seafood, Crisfield, MD.)**

Please RSVP to Gail @ 410-651-6625 or alallen@umes.edu



University of Maryland Eastern Shore
USDA Agricultural Research Service
Fact Sheet

"THE GYPSUM CURTAIN PROJECT"

Using Flue Gas Desulfurization (FGD) Gypsum To Minimize Dissolved Phosphorus Loss from Soils

Ray B. Bryant and Arthur L. Allen

The gypsum curtain project is a partnership effort among the University of Maryland Eastern Shore, USDA Agricultural Research Service, Exelon Corporation-Constellation Energy (ECCE), and The University of Maryland. The project is funded by a USDA Natural Resources Conservation Innovation Grant at $1 million with $1 million in matching from ECCE in the form of flue gas desulfurization (FGD) gypsum delivered to the farm sites.

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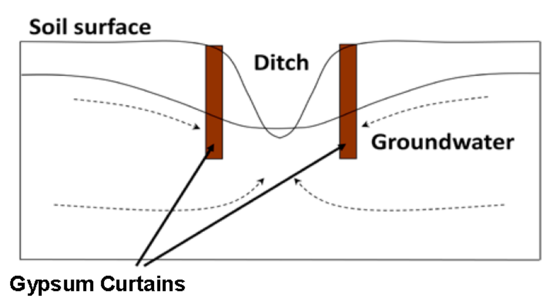
2. Obtain producers' evaluations of this practice in the context of whole farm operations,
3. Adjust the practice to address producers' concerns if necessary, and
4. Work in concert with NRCS personnel and others to develop standards for this practice.

Background

The Delmarva Peninsula houses a robust poultry industry that has been scrutinized for its contributions of nutrients to the Bay. UMES and USDA-Agricultural Research Service (ARS) researchers have documented substantial P concentrations in agricultural drainage waters derived from high P soils (350 to 550 mg kg^{-1} Mehlich-3 P) that have received poultry litter for decades. Even when these soils receive no P additions, losses due to soluble P moving through groundwater result in P concentrations in ditches of 2 to 4 mg L^{-1}.

Research conducted at the UMES Agricultural Experiment Station has documented the effectiveness of a novel practice - the gypsum curtain. FGD gypsum, a byproduct of coal-fired power generation, is used to precipitate dissolved P and thereby reduce P concentrations in groundwater before it enters the drainage ditch. In sandy soils and well structured fine textured soil on flat landscapes of the Eastern Shore, downward leaching and lateral flow of water containing high concentrations of soluble P derived from legacy P sources is the dominant pathway of P movement from field to ditch.



Methods

Ditch curtains are installed by excavating trenches (1 ft wide) parallel to the ditch or tile drain and backfilling them with gypsum. The solubility of gypsum supports a high concentration of calcium in solution that reacts with soluble P to form an insoluble calcium phosphate precipitate, which can be excavated and removed from the watershed or left buried in an insoluble particulate form.

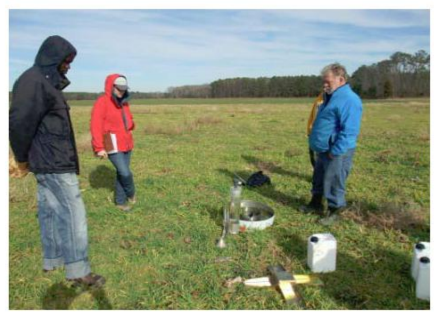
A trencher is used to open a one foot wide trench. The depth of the trench varies between 2 and 4 feet deep depending on soil conditions that may limit excavation, as sandy soils may be susceptible to caving. Since high P concentrations have been observed at shallow depths when conditions are wet and groundwater is flowing, the shallower trench depth may be nearly as effective as the deeper trench, thereby affecting the recommended standard for maximum efficiency of curtain construction for effective P removal.

A Mensch Trailer Mounted Side Shooter was purchased for use in delivering the gypsum to the trench. The Side Shooter is designed to allow the operator to clearly see and control gypsum delivery to the trench.

The gypsum-filled trench is then covered with topsoil and smoothed to its original contour using a front loader bucket or blade.

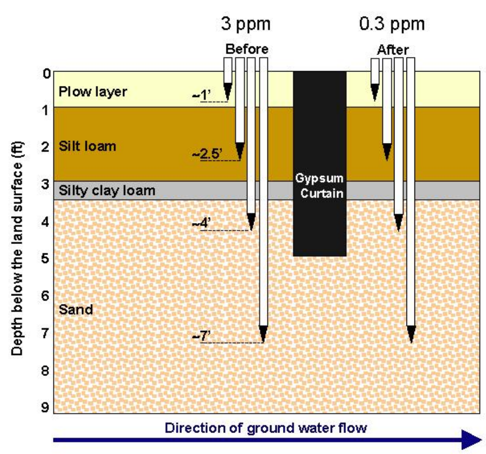
Using a litter spreader, gypsum is also being surface applied to improve soil structure, enhance infiltration, and reduce soluble P in surface soils.

Infiltrometer measurements are being made to measure the effects of gypsum application.



Effectiveness

Preliminary results show a 90% reduction in dissolved P concentration in groundwater that passes through the gypsum curtain.



Producers are assessing disturbance to fields and farm operations. Contractors are assessing costs and practical aspects of installation.