ENVIRONMENTAL FINANCE CENTER

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MEMORANDUM

To: Sustainable Chesapeake

From: University of Maryland Environmental Finance Center

Date: October 5, 2017

Re: Considerations for Evaluating the Relative Cost Effectiveness of Subsurface Manure Injection and its Adoption in the Chesapeake Bay Watershed

This document presents data that may be used to evaluate the relative cost effectiveness of subsurface manure injection as a practice for managing agricultural nutrient and sediment pollution within the Chesapeake Bay watershed.

Background

Manure incorporation is broadly defined as "the mixing of dry, semi-dry, or liquid organic nutrient sources (including manures, biosolids, and compost) into the soil profile within a specified time period from application by a range of field operations."[1] Manure injection is a particular category of incorporation in which nutrient sources are mechanically applied below the soil surface near the crop's root zone. Subsurface manure injection has been shown to reduce nutrient loss via both atmospheric volatilization and surface runoff, to limit soil disruption and erosion, and to reduce the odor associated with manure application.[2] This practice has been recommended by an expert review panel to be eligible for credit in the Chesapeake Bay Program Partnership's Watershed Model.[3]

Adoption of subsurface manure injection technology will be influenced by how it compares to traditional best management practices (BMPs) for treating agricultural pollution, in terms of both environmental outcomes and cost competitiveness. To assist in gauging its adoption potential, EFC was asked to synthesize the available information on the cost effectiveness of existing agricultural BMPs, and to provide information about the potential scale of the technology's utilization throughout the Chesapeake Bay watershed based on the relative number of acres to which it could be applied.

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[1] Chesapeake Bay Program Phase 6.0 Nutrient Management BMP Expert Panel. November 2016. "Draft BMP Panel Report: Definitions and Recommended Nutrient Reduction Efficiencies of Manure Injection & Incorporation Practices."

[2] Chesapeake Bay Program Phase 6.0 Nutrient Management BMP Expert Panel. November 2016. "Draft BMP Panel Report: Definitions and Recommended Nutrient Reduction Efficiencies of Manure Injection & Incorporation Practices." and Lui, J. et al. Oct 2013. "Subsurface application enhances benefits of manure redistribution." *Crops and Soils magazine.*

[3] The panel recommended three manure injection and incorporation practices for approval. See: Chesapeake Bay Program Phase 6.0 Nutrient Management BMP Expert Panel. November 2016. "Draft BMP Panel Report: Definitions and Recommended Nutrient Reduction Efficiencies of Manure Injection & Incorporation Practices."

Agricultural BMP cost effectiveness data

Through a literature review, EFC identified cost effectiveness estimates for agricultural best management practices, represented as the cost of preventing one pound of nitrogen pollution from being delivered to the receiving water body per year. Both nitrogen and phosphorous are pollutants of concern in the Chesapeake Bay watershed, and most BMPs will impact both pollutants (but with varying degrees of efficiencies). However, the literature review revealed that cost effectiveness information tends to focus on nitrogen, rather than phosphorous.[4]

Table 1, below, presents a summary of EFC's findings. Estimates are available for a variety of BMPs. Practices include structural approaches (water control devices, manure containment facilities), green infrastructure strategies (restored wetlands, vegetated buffers), agricultural management practices (contour farming, prescribed grazing), and policy solutions (manure transport, chicken house buyouts). Further, practices tend to be commodity-specific rather than generally applicable across a variety of agricultural production categories, such as cropland, pasture, grazing lands, and animal feeding facilities.

Table 1. Cost effectiveness of agricultural BMPs

	Cost / lb N removed / year ($)				
BMP	Average of all estimates	Low estimate	High estimate	Source codes (see below)	Notes
Contour farming	0.10	0.10	0.10	3	
Strip cropping	0.22	0.22	0.22	3	
Terraces w/ vegetated outlets	1.11	1.11	1.11	3	
Chicken house buyout	1.37	1.37	1.37	4	
Nutrient removal wetlands	1.38	1.38	1.38	3	
Manure transport	2.77	2.77	2.77	4	
Drainage water management	2.83	1.48	4.17	3	
Animal waste management systems	4.89	2.38	10	4	Estimates for MD, PA, and VA

[4] University of Maryland School of Public Policy, Policy Analysis Workshop, Robert Nelson Professor. 2005. *A Bigger Bang for the Buck: Offsets and Other Cost-Effective Strategies for Nitrogen Reductions for the Chesapeake Bay.* Available: http://riverfriendlyyard.com/wp-content/uploads/2012/07/A-BIGGER-BANG-FOR-THE-BUCK-OFFSETS-AND-OTHER-COST-EFFECTIVE-STRATEGIES-FOR-NITROGEN-REDUCTIONS-FOR-THE-CHESAPEAKE-BAY.pdf

Grassed buffers	8	40	50	1 - 5	1. "Grassed buffers and vegetated open channels" 2. High & low estimates 3. Includes two BMPs: "Buffers and vegetated filters with no-till" and "Buffers and vegetated filters with typical tillage"; high and low estimates 4. Estimates for MD, PA, and VA
Livestock exclusion	10	0	15	2, 4	2. High & low estimates 4. "Stream protection w with fencing"; estimate for PA
Cover crops	11	1	60	1 - 5	1. "Cover crop standard drilled wheat" 2. "Cover crop / early drilled rye"; high & low estimates 3. "Annual cover crops"; high & low estimates 4. "Cover crops early"; estimates for MD, PA and VA
Water control structures	14	14	14	1	
Conservation tillage	16	0	50	1 - 5	2. "Continuous no-till"; high & low estimates 3. "No-till" 4. Estimates for MD and PA
Conservation plans	22	5	44	4	Estimates for MD, PA, and VA
Nutrient management	24	2	90	1, 2, 4, 5	1. "Enhanced nutrient management" 2. "Enhanced nutrient management"; high & low estimates 4. Estimates for MD and VA 5. "Enhanced nutrient management plans"
Land retirement	33	2	115	1, 2, 4	1. Includes two BMPs: "Land retirement to hay without nutrients" and "Land retirement to pasture" 2. High & low estimates 4. Estimates for MD and PA
Forested buffers	40	15	90	1, 2	2. High & low estimates

Loafing lot management	59	59	59	1	
Barnyard runoff control	66	66	66	1	
Wetland restoration	109	28	260	1, 2	2. High & low estimates
Tree planting	145	40	250	2	2. High & low estimates
Decision agriculture	192	26	480	1, 2	2. High & low estimates
Off-stream watering	199	18	590	2, 4	2. High and low ends of apparent range 4. "Off-stream watering with fencing" -- estimates for MD and VA
Prescribed grazing	521	50	1333	1, 2	2. "Upland prescribed grazing"; high & low estimates
Intensive / rotational grazing	588	175	650	1, 2	1. "Precision intensive rotational grazing" 2. "Upland precision / rotational grazing"; high and low ends of apparent range
Non-urban stream restoration; shoreline erosion control	667	667	667	1	
Cropland irrigation management	2341	2341	2341	1	

Sources:
1. Maryland Department of the Environment. 2013. *Estimated costs of BMPs that could generate N reductions for trading.* Available: http://mde.maryland.gov/programs/water/TMDL/TMDLImplementation/Documents/AccountforGrowth/Meeting_Materials/Meeting7/Estimated_costs_BMPs_N.pdf
2. Chesapeake Bay Commission. May 2012. *Nutrient Credit Trading for the Chesapeake Bay: An Economic Study*. Available: http://www.chesbay.us/Publications/nutrient-trading-2012.pdf. Note: CBC's report did not include precise cost values but rather represented values on a chart, from which EFC approximated the values found within this report.
3. Wortman, Charles et al. 2011. *Cost-effective Water Quality Protection in the Midwest.* Available: http://extensionpublications.unl.edu/assets/pdf/rp197.pdf
4. University of Maryland School of Public Policy, Policy Analysis Workshop, Robert Nelson Professor. 2005. *A Bigger Bang for the Buck: Offsets and Other Cost-Effective Strategies for Nitrogen Reductions for the Chesapeake Bay.* Available: http://riverfriendlyyard.com/wp-content/uploads/2012/07/A-BIGGER-BANG-FOR-THE-BUCK-OFFSETS-AND-OTHER-COST-EFFECTIVE-STRATEGIES-FOR-NITROGEN-REDUCTIONS-FOR-THE-CHESAPEAKE-BAY.pdf
5. Newburn, David. Undated. "Fundamentals of Nutrient Trading" presentation slides. Available: http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/Nutrient_Trading_Symposium_Jan2016/5_David_Newburn_Presentation.pdf

The range of cost effectiveness for agricultural BMPs is wide, both within practices and between them. Sizable gaps between the high and low estimates for several BMPs may reflect not only differences in study methodologies but also the fact that cost effectiveness can vary for any given BMP based on where it is installed within the watershed and other factors. Across the BMPs, cost effectiveness ranges from a low of $0.10/lb (contour farming) to a high of $2,341/lb (cropland irrigation management). However, this large span is somewhat misleading due to outliers on the high end of the range. Half of the estimates fall below $22/lb. Three-quarters of the estimates fall below $128/lb.

Practices with the lowest values are generally those for which only one source in the literature was available, indicating that these practices' low cost may be due to a single low estimate rather than their actual cost effectiveness. In contrast, practices with average or high cost effectiveness values typically have multiple sources and estimates. Further research is needed to enable a more accurate evaluation of relative agricultural BMP cost effectiveness.

It is important to note limitations of data found in the literature. While the table presents estimates for nearly 30 agricultural BMPs, they come from five sources:

- A 2012 economic study by the Chesapeake Bay Commission on nutrient credit trading in the Bay watershed;[5]
- a 2005 policy analysis by University of Maryland on cost-effective strategies for nitrogen reduction;[6]
- information assembled by the Maryland Department of the Environment on estimated BMP costs for application in a water quality trading context;[7]
- a study by the Heartland Regional Water Coordination Initiative on cost-effective water quality protection in the Midwest;[8] and
- information from the Department of Agricultural and Resource Economics at the University of Maryland.[9]

These sources rely on a deeper body of research to construct the cost-effectiveness estimates. Variation in the computational and analytic assumptions underpinning the estimates will limit the extent to which they can be appropriately compared. For example, it is not possible to determine which components of full-cost accounting (e.g., one-time capital and installation costs, land costs, and yearly operations and maintenance costs) are included in all estimates. Other important assumptions that can significantly impact the estimates include assumed operational life, discount rates, and use of real or nominal dollars. These limitations suggest that caution is warranted in drawing firm conclusions from the information presented in the table.

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[5] Chesapeake Bay Commission. May 2012. *Nutrient Credit Trading for the Chesapeake Bay: An Economic Study.* Available: http://www.chesbay.us/Publications/nutrient-trading-2012.pdf. Note: CBC's report did not include precise cost values but rather represented values on a chart, from which EFC approximated the values found within this report.

[6] University of Maryland School of Public Policy, Policy Analysis Workshop, Robert Nelson Professor. 2005. *A Bigger Bang for the Buck: Offsets and Other Cost-Effective Strategies for Nitrogen Reductions for the Chesapeake Bay.* Available: http://riverfriendlyyard.com/wp-content/uploads/2012/07/A-BIGGER-BANG-FOR-THE-BUCK-OFFSETS-AND-OTHER-COST-EFFECTIVE-STRATEGIES-FOR-NITROGEN-REDUCTIONS-FOR-THE-CHESAPEAKE-BAY.pdf

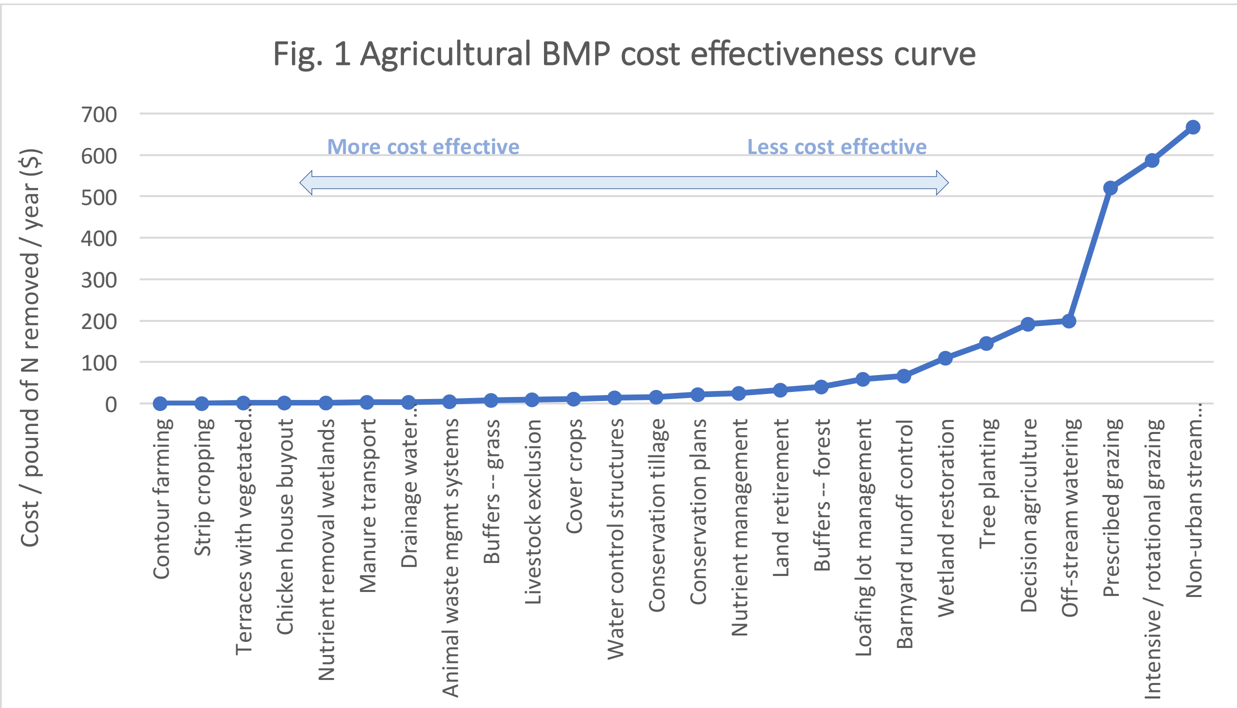
[7] Maryland Department of the Environment. 2013. *Estimated costs of BMPs that could generate N reductions for trading.* Available: http://mde.maryland.gov/programs/water/TMDL/TMDLImplementation/Documents/AccountforGrowth/Meeting_Materials/Meeting7/Estimated_costs_BMPs_N.pdf

[8] Wortman, Charles et al. 2011. *Cost-effective Water Quality Protection in the Midwest.* Available: http://extensionpublications.unl.edu/assets/pdf/rp197.pdf

[9] Newburn, David. Undated. "Fundamentals of Nutrient Trading" presentation slides. Available: http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/Nutrient_Trading_Symposium_Jan2016/5_David_Newburn_Presentation.pdf

Cost effectiveness curve

EFC used the above data to construct a nutrient abatement curve for the agricultural sector, which is presented in Figure 1, below. The curve orders practices from most cost effective to least cost effective. It excludes cropland irrigation management, as this practice's estimated cost is more than twelve times higher than the next-highest practice.[10] The majority of practices fall below $100/lb of nitrogen removed per year. More cost-effective practices include contour farming, strip farming, chicken house buyout, and manure transport. Less cost-effective practices include stream restoration, intensive and prescribed grazing, wetland restoration, and off-stream watering.



Sources: see references at the end of Table 1.

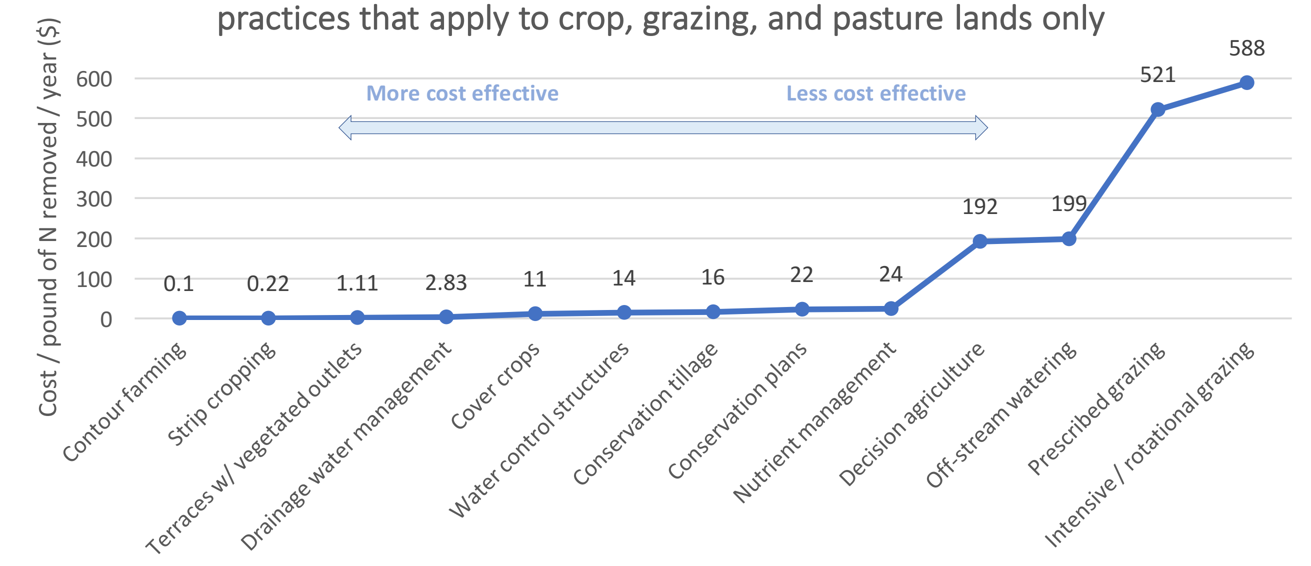
Not all practices in the abatement curve are substitutes for or complements to each other. As a result, the abatement curve's composition and shape will look differently by farming practice and commodity. Selecting only those practices that apply to crop and pasture lands enables a more refined assessment of where subsurface manure injection might lie within the competitive landscape, as these are the types of land on which subsurface injection could be used.

Manure injection practices apply to the following land uses within the Chesapeake Bay Watershed Model: full season soybeans, grain with manure, legume and other hay, silage with manure, small grains and

[10] Further, a cost effectiveness value for this particular BMP could be found in only one source in the literature.

grains, specialty crop high, specialty crop low, other agronomic crops, and pasture.[11] Thirteen practices from the full set of BMPs apply to similar land uses. The cost effectiveness of these practices is portrayed in Figure 2, below. Cost effectiveness for this group of practices ranges from $0.10/lb of nitrogen removed each year for contour farming to $588/lb for intensive/rotational grazing (excluding cropland irrigation management). This group of practices tends to account for some of the more cost effective BMPs. The median value for these thirteen practices is $16/lb (compared to the median of all agricultural BMPs, $22/lb). The mean value is $122/lb, although as above the majority of practices (69%) fall below this figure.

Figure 2. Agricultural BMP cost effectiveness curve - practices that apply to crop, grazing, and pasture lands only



Sources: see references at the end of Table 1.

Potential scale of manure injection adoption

The potential of subsurface manure injection to be widely adopted throughout the Chesapeake Bay region depends on various factors, including the practice's agronomic, environmental, financial and regulatory impacts. From a state policy perspective, another important factor that could influence whether this practice is promoted relative to other practices is the *acreage* to which it could be applied.

As mentioned, subsurface injection can be used on crop and pasture lands on which manure is permitted to be applied. Table 2, below, details the total acreage devoted to various agricultural activities within

[11] These land use categories apply to the updated version of the Watershed Model, Phase 6. Source: Chesapeake Bay Program Phase 6.0. Source: Nutrient Management BMP Expert Panel. November 2016. "Draft BMP Panel Report: Definitions and Recommended Nutrient Reduction Efficiencies of Manure Injection & Incorporation Practices."

the Chesapeake Bay watershed and identifies which acres are potential candidates for the technology's application. According to the Chesapeake Bay Watershed Model, 90% of cropland in the watershed – or approximately 11 million acres – is under manure-eligible conventional tillage or manure-eligible conservation tillage.[12] Since subsurface injection is compatible with both conventional and conservation tillage, this practice could potentially be used on the vast majority of cropland within the Chesapeake Bay watershed. An additional 5.1 million acres in the watershed is pasture land, which is also potentially eligible for subsurface manure injection. Combined, an estimated 14.5 million acres, or 89.6% of all agricultural land in the Chesapeake Bay watershed, is potentially available for the use of this technology.

Table 2. Total acreage in agricultural land use categories, Chesapeake Bay Watershed Model Phase 5.3

Agricultural land use category	Total acreage	Eligible for subsurface manure injection
Alfalfa	1,028,648	Y
Degraded riparian pasture	182,324	
Hay with nutrients	2,411,777	Y
Hay without nutrients	811,833	
High till with manure	1,786,506	Y
High till without manure	490,129	
Low till with manure	1,192,050	Y
Non-CAFO animal feeding operations	31,352	
Nursery	36,374	
Nutrient management alfalfa	331,709	Y
Nutrient management hay	604,483	Y
Nutrient management high till with manure	827,899	Y
Nutrient management high till without manure	132,152	
Nutrient management low till	1,180,333	Y
Nutrient management pasture	210,410	Y
Pasture	4,926,132	Y
Total acreage available for subsurface injection		14.5 million

Land use data is for the Phase 5.3 Watershed Model for the year 2005. Source: Chesapeake Community Modeling Program. "Model Input." Accessed 9/26/17: http://ches.communitymodeling.org/models/CBPhase5/datalibrary/model-input.php

Table 3, below, reports agricultural acreage by state in the Chesapeake Bay watershed. Across the six states, nearly 22.5 million acres could potentially employ subsurface injection technology. The acreage is split between two categories: (i) cropland and (ii) grassland, pasture and range. Consideration of how

[12] USEPA (U.S. Environmental Protection Agency). 2010. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA 903S10002 - CBP/TRS-303-10. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis MD. December 2010.

agricultural activity breaks down across the states and these two categories is another possibly important factor. Each state has unique guidelines in terms of agricultural best management practices and water quality recommendations. Further, the expert review panel did not recommend this technology for credit in the Chesapeake Bay Watershed Model when applied to rangeland.[13]

Table 3. Acreage potentially available for subsurface manure injection, Chesapeake Bay states

State	**Cropland** (1,000 acres)	**Grassland, pasture and range** (1,000 acres)	**Total land area** (1,000 acres)	**Percentage of total land potentially available for subsurface injection**
Delaware	438	18	1,247	37%
Maryland	1,277	447	6,212	28%
New York	4,247	2,397	30,161	22%
Pennsylvania	4,517	1,287	28,636	20%
Virginia	2,989	2,794	25,274	23%
West Virginia	781	1,351	15,384	14%
TOTALS	14,249	8,294	106,914	21%

Source: U.S. Department of Agricultural Economic Research Service. "Major uses of land by region and State, United States, 2012." Updated 8/28/17. Available: https://www.ers.usda.gov/data-products/major-land-uses/

These figures suggest that there is ample acreage available throughout the Chesapeake Bay watershed for the potential utilization of subsurface manure injection. Further, several drivers support the widespread adoption of this technology in the region, including the US EPA Chesapeake Bay Total Maximum Daily Load (TMDL), which requires Bay states to reduce pollutant loading to the Bay. As states seek to comply with the TMDL's agricultural load limits, a prevalent BMP is conservation tillage (low-till or no-till) or perennial grass cover; these are used on the majority (60%) of agricultural land in the watershed.[14] Given the importance of conservation tillage for TMDL compliance and for local water quality, manure management practices that are compatible with conservation tillage will likely become increasingly in demand.

To capitalize on manure injection's adoption potential, applicator technologies will need to prove environmentally effective, user-friendly, and affordable. The agricultural BMP cost effectiveness information presented in this report – while tempered by the noted data limitations – may be used by developers of manure injection technologies to set a target value for their technology's cost effectiveness. BMP cost effectiveness information may also be used in policy contexts to determine where manure injection falls on the abatement curve relative to alternative practices.

[13] Chesapeake Bay Program Phase 6.0 Nutrient Management BMP Expert Panel. November 2016. "Draft BMP Panel Report: Definitions and Recommended Nutrient Reduction Efficiencies of Manure Injection & Incorporation Practices."
[14] Maguire 2011 in Lui, J. et al. Oct 2013. "Subsurface application enhances benefits of manure redistribution." *Crops and Soils magazine.*