CONTINUOUS HIGH RESIDUE, MINIMUM SOIL DISTURBANCE BMP

Definition and Recommended Sediment Reduction Efficiencies for Use in Phase 5.3.2 of the Chesapeake Bay Program Watershed Model

Recommendations for Approval by the Water Quality Goal Implementation Team's Watershed Technical and Agricultural Workgroups

Introduction

This document summarizes the recommendations of the Conservation Tillage Expert Panel for the revised tillage practice of Continuous High Residue, Minimum Soil Disturbance (HR), including a new practice definition and efficiency estimates for inclusion in the Phase 5.3.2 of the Chesapeake Bay Program Watershed Model. The report was approved and enacted for 2013 progress by the Water Quality Goal Implementation Team on October 15, 2013. This practice represents the highest level of soil conservation and soil cover management to improve soil organic matter content and soil quality, and to reduce runoff and sediment and nutrient losses. This practice is proposed to provide stackability with other best management practice (BMP) reductions, such as cover crops and nutrient management. HR will only be placed on acres of agricultural land already reported under conservation tillage. The HR BMP can be placed on the Watershed Model land uses, LWM (low-till with manure) and NLO (nutrient management low-till). This BMP is intended to replace the current CNT (continuous no-till) practice.

This document summarizes adopted recommendations and plans for future recommendations of the 2012-13 Conservation Tillage Expert Panel for nitrogen (N), phosphorus (P), and sediment reduction efficiencies associated with high-residue, minimum soil disturbance cropland management.

Panel Members

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Practice Definition: Continuous High-Residue Minimum Soil-Disturbance (HR)
A high degree of soil cover dramatically increases water infiltration and storage, and decreases soil erosion and soil-bound nutrient losses. Over time, this practice also typically results in increased N retention in soil due to increased soil organic matter content. The Continuous No-Till (CNT) practice was proposed for inclusion in the Bay Model in 2005. CNT is considered an enhanced version of the Conservation Tillage BMP and thus can be applied to a subset of the acres receiving Conservation Tillage. However in previous iterations, the N, P, and sediment reduction efficiencies associated with CNT were inclusive of reductions due to Nutrient Management and Cover Crops, both associated cropland BMPs. In order to maximize the potential impact of the panels' limited time and scope for potential revisions to the overall set of conservation tillage practices, the panel decided to focus emphasis directly on a "stackable" CNT practice. After considerable time spent reviewing the literature and discussing the various effects of no-till practices, the panel agreed that the preponderance of evidence indicates that a high degree of soil cover, over 60%, has the greatest impact on water quality benefits. Research from soils and cropping systems within the Chesapeake Bay watershed and from similar conditions elsewhere suggests the effects on infiltration and sediment loss are predominantly determined by residue cover and not by soil disturbance, per-se.

The Continuous High-Residue Minimum Soil-Disturbance (HR) BMP definition does not currently exist in the model but is intended to replace the current CNT practice. The HR BMP is a new crop planting and residue management practice in which soil disturbance by plows and implements intended to invert residue is eliminated. Any disturbance must leave a minimum of 60% crop residue cover on the soil surface as measured after planting. HR involves all crops in a multi-crop, multi-year rotation and the crop residue cover requirement (including living or dead material) is to be met immediately after planting of each crop.

The purpose of implementing the HR BMP is to improve soil organic matter content and soil quality, and to reduce runoff and sediment and nutrient losses coupled with a continuous high-residue management system. Multi-crop, multi-year rotations on cropland are eligible. The system must be maintained for a minimum of one full crop rotation, and tracked and reported on an annual basis.

The Chesapeake Bay Watershed Model has hi-till (0-29% crop residue or conventional tillage) crop land-uses and low till (30+% crop residue or conservation tillage) land-uses, but does not have an explicit land use that defines the properties of HR with minimum soil disturbance. Because HR will be considered a sub-set of the current conservation tillage land use, it is necessary to calculate the effects of HR as reduction efficiency relative to the efficiency already achieved by the conservation tillage land use. The HR practice can be combined with other associated, applicable BMPs for additional reductions, including nutrient management and cover crops.

Applicable USDA-NRCS Practices

No current USDA Natural Resource Conservation Service (NRCS) Conservation Practice standards are directly applicable to this practice. NRCS residue management practice standards are based on the Soil Tillage Intensity Rating (STIR) rather than the percent cover remaining after planting. All related practice standards describe practices to be implemented or avoided. The HR BMP is defined based on outcomes (>60% residue cover), not a particular practice or set of practices.

Effectiveness Estimates

Table 1. Proposed relative reduction efficiency estimates

Panel Proposed HR BMP	
Total N Uplands- unmanured Continuous High-Residue Minimum Soil-Disturbance lbs/acre Low-Till → Continuous HR (Stackable) Load Reduction -5.25%	Total N Coastal Plain- unmanured Continuous High-Residue Minimum Soil-Disturbance lbs/acre Low-Till → Continuous HR (Stackable) Load Reduction -2.25%
Total P Uplands- unmanured Continuous High-Residue Minimum Soil-Disturbance lbs/acre Low-Till → Continuous HR (Stackable) Load Reduction -10%	Total P Coastal Plain- unmanured Continuous High-Residue Minimum Soil-Disturbance lbs/acre Low-Till → Continuous HR (Stackable) Load Reduction -5%
Total Suspended Solids Uplands Continuous High-Residue Minimum Soil-Disturbance tons/acre Low-Till → Continuous HR (Stackable) Load Reduction -64.0%	Total Suspended Solids Coastal Plain Continuous High-Residue Minimum Soil-Disturbance tons/acre Low-Till → Continuous HR (Stackable) Load Reduction -64.0%

Sediment

The panel found ample evidence in the existing literature comparing sediment losses from conservation tillage systems with those of high residue examples, generally from no-till systems. In many cases the cited work did not provide estimates of soil cover after the conservation tillage practice was applied, however the professional judgment of the panel was that the practices indicated would likely produce the minimum 30% residue for the Conservation Tillage category. Also in support of this was that the RUSLE2 estimates of sediment loss reduction calculated by NRCS for typical agricultural cropland soils in Pennsylvania and Virginia were very similar to the values from literature and these runs were conducted with at least 30% soil cover estimates for the conservation tillage practice.

In general, small plot studies with simulated rainfall produced higher reduction estimates than the watershed-scale studies, which the panel assumed to be more reliable and indicative of real-world conditions. Therefore, the panel decided to reduce reported erosion reduction values from small plot studies by 15% to compensate for this effect (Table 2). Values from watershed-scale studies, small plot experiments, and RUSLE2 simulation were evaluated for corroboration. While the absolute values for sediment losses varied by region, soil, and slope the relative reduction was similar across the watershed. The panel recommends a single efficiency value of 64% sediment reduction for this practice, based on averaging applicable reported efficiencies.

Table 2. Reported sediment reduction values of high residue systems over conservation tillage from applicable peer-reviewed studies and RUSLE2 model runs.

Brief Citation	% sediment reduction, Conservation Till to High-Res, Min Disturbance (NT)
Small Watershed-scale studies	
Shipitalo and Edwards, 1998	-61.5%
Staver, 2004	-67.5%
AVG	**-64.5%**
Small plot studies	
Verbree et al, 2010	-85.2%
Truman e al., 2005	-91.5%
Benham et al., 2007	-77.2%
Eghball and Gilley, 2001	-79.6%
Kleinman et al., 2009	-38.0%
AVG	**-74.3%**
15% small plot adjustment	**-63.1%**
RUSLE2 model runs	
Coastal Plain, 1% slope	-49%
Coastal Plain, 2% slope	-80%
Coastal Plain, 4% slope	-78%
Piedmont, 3-4% slope	-65%
Piedmont, 5-6% slope	-68%
Piedmont, 9-10% slope	-58%
Ridge & Valley, 3-4% slope	-66%
Ridge & Valley, 5-6% slope	-71%
Ridge & Valley, 9-10% slope	-70%
Plateau, 4% slope	-75%
Plateau, 6% slope	-77%
Plateau, 10% slope	-76%
AVG	**-69.4%**

Phosphorus
The panel recommends zero reduction in P from the implementation of the HRMSD practice on manured acres. Because of the difference in the major P loss pathways between Coastal Plain and upland soils, we suggest that a 5% reduction in P loss be credited to implementation of this practice in the Coastal Plain, but that a 10% reduction in P losses occurs when HRMSD is implemented on upland soils were sediment-bound P losses dominate. The determination of acres receiving manure or not receiving manure will be based on USDA-NASS census data. This will be calculated at the smallest possible land unit, i.e. County. The differentiation between acres that receive manure and those that do not (assumed to receive crop P requirement from inorganic sources) is based on the assumption that higher soil test P levels typically occur with a history of manure application and that with very high STP, dissolved P losses make up a much greater proportion of total losses, making the sediment loss reductions for HRMSD less impactful on total P losses.

Nitrogen
The panel recommends that an N loss reduction of 2.25 and 5.25% be applied to non-manured acres in the Coastal Plain and Upland regions, respectively due to implementation of the HRMSD practice. These values are calculated from the base assumption that HRMSD results in a 15% decrease in N loss through surface pathways, and so would not apply to the proportion of water flow attributed to infiltration. In the Coastal Plain the surface movement is estimated to make up 15% of total water flow from the system, while in Upland areas, 35% of water is estimated to move through the surface loss pathway. Those values are based on water outflow partitioning coefficients estimated by the USGS and also used in the estimate of cover crop efficiencies for N in the MAWP/UMD BMP report.

Recommendation and associated benefits
The panel is currently recommending that the HR practice and sediment reduction values recommended for HR be treated as stackable with other applicable agricultural cropland BMPs on lo-till land uses. At this time, the stackable HR practice would be given no N or P reduction credit; however, any reduction values associated with other practices applied to that same area would be included. The same acre could not be reported to CNT and HR. States must choose if they will submit HR or CNT. States cannot submit HR in one county and CNT in another county for the same scenario.
In addition to the direct benefit of reduced erosion, reduced tillage cropping systems are often more profitable for farmers, retain more soil water, and result in higher soil organic matter levels over time. Less fuel usage can also reduce the carbon footprint associated with crop production.

The panel found no instances in the literature where this practice increased sediment losses or where pollutants (sediment) were relocated to a different location or loss mechanism. The panel was diligent about selecting data on sediment losses that would be representative of this practice alone and not dependent on the inclusion of other potential BMPs such as cover crops or nutrient management. The RUSLE2 simulations included only crop residue, with no cover crops included, to reach the minimum required levels of soil cover. However these factors can definitely interact and can synergistically enhance environmental benefits.

References

Andraski B.J., Mueller D.H., Daniel T.C. (1985) Phosphorus Losses in Runoff As Affected by Tillage. Soil Sci. Soc. Am. J. 49:1523-1527. DOI: 10.2136/sssaj1985.03615995004900060038x.

Benham B., Vaughan D., Laird M., Ross B., Peek D. (2007) Surface Water Quality Impacts of Conservation Tillage Practices on Burley Tobacco Production Systems in Southwest Virginia. Water, Air, and Soil Pollution 179:159-166. DOI: 10.1007/s11270-006-9221-z.

Bundy L.G., Andraski T.W., Powell J.M. (2001) Management practice effects on phosphorus losses in runoff in corn production system. J. Environ. Qual. 30:1822-28.

Eghball B., Gilley J.E. (2001) Phosphorus risk assessment index evaluation using runoff measurements. J. Soil Water Cons. 56:202-206.

Kimmell R.J., Pierzynski G.M., Janssen K.A., Barnes P.L. (2001) Effects of Tillage and Phosphorus Placement on Phosphorus Runoff Losses in a Grain Sorghum–Soybean Rotation Contribution no. 00-358-J from the Kansas Agric. Exp. Stn. J. Environ. Qual. 30:1324-1330. DOI: 10.2134/jeq2001.3041324x.

Kleinman P.A., Sharpley A., Saporito L., Buda A., Bryant R. (2009) Application of manure to no-till soils: phosphorus losses by sub-surface and surface pathways. Nutrient Cycling in Agroecosystems 84:215-227. DOI: 10.1007/s10705-008-9238-3.

Kleinman P.J.A., Sharpley A.N., Moyer B.G., Elwinger G.F. (2002) Effect of Mineral and Manure Phosphorus Sources on Runoff Phosphorus. J. Environ. Qual. 31:2026-2033. DOI: 10.2134/jeq2002.2026.

Quincke J.A., Wortmann C.S., Mamo M., Franti T., Drijber R.A., García J.P. (2007) One-Time Tillage of No-Till Systems. Agron. J. 99:1104-1110. DOI: 10.2134/agronj2006.0321.

Sharpley A.N., Smith S.J., Williams J.R., Jones O.R., Coleman G.A. (1991) Water Quality Impacts Associated with Sorghum Culture in the Southern Plains. J. Environ. Qual. 20:239-244. DOI: 10.2134/jeq1991.00472425002000010038x.

Shipitalo M.J., Edwards W.M. (1998) Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. Soil Till. Res. 46:1-12.

Staver K.W. (2004) Efficient utilization of poultry litter in cash grain rotations. Final Report submitted to: Maryland Grain Producers Utilization Board. MCAE Pub. 2004-03.

Truman C.C., Shaw J.N., Reeves D.W. (2005) Tillage effects on rainfall partitioning and sediment yield from an ultisol in central Alabama. Journal of Soil and Water Conservation 60:89-98.

Verbree D.A., Duiker S.W., Kleinman P.J.A. (2010) Runoff losses of sediment and phosphorus from no-till and cultivated soils receiving dairy manure. J. Environ. Qual. 39:1762-1770.

<u>References used for sediment estimates</u>

Shipitalo and Edwards, 1998
Staver, 2004
Verbree et al, 2010

Truman e al., 2005
Benham et al., 2007
Eghball and Gilley, 2001
Kleinman et al., 2009

Results from these references were averaged to arrive at the proposed efficiency estimates; reductions reported by small plot studies were discounted 15% as discussed previously (see Table 2).

Results reported in the literature reviewed for sediment and P reduction efficiencies are summarized in an attachment to this report.

All citations and data used in developing the sediment loss reduction values were from studies conducted in the CB region or on very similar soils under similar cropping systems. In general, small plot studies with simulated rainfall produced higher reduction estimates than the watershed-scale studies, which the panel assumed to be more reliable and indicative of real-world conditions. Therefore, the panel decided to reduce reported erosion reduction values from small plot studies by 15% to compensate for this effect (Table 2). Values from watershed-scale studies, small plot experiments, and RUSLE2 simulation were evaluated for corroboration. Specific information about each study cited is included in Appendix A.

Application of Practice Effectiveness Estimates

- Units of measure: acre
- Load sources addressed: 64% sediment reduction over that credited for low-till with manure (LWM).
- Conditions under which the BMP works: Relative effectiveness for sediment reduction is similar across regions, soils, and slopes. Uneven distribution of cover could decrease effectiveness.
- Considerations for benefits in load reduction: The panel reviewed and included seven peer-reviewed studies over a wide range of soil textures, slope and drainage. Because all studies reported similar relative sediment efficiency values, the panel did not differentiate by texture, etc. In our findings, there were no changes in load reductions among soil textures. Sediment values are only relevant as surface transport. Subsurface and other pathways relevant for nutrient losses are not relevant for sediment.

Geographic Considerations

- This practice is applicable to lo-till row crop land throughout the watershed.
- Load reduction estimates reflect edge-of-field reductions.
- The baseline condition was Conservation Tillage, as currently defined. Efficiency values represent reductions relative to this baseline.

- The same sediment reduction efficiency is appropriate across the watershed.

Temporal Considerations

- HR involves all crops in a multi-crop, multi-year rotation and the crop residue cover requirement (including living or dead material) is to be met immediately after planting of each crop in rotation.
- The practice will be tracked and reported annually.
- The practice is expected to provide full benefits at all times when the minimum residue cover is in place and effecting as long as that condition persists.
- The efficacy of this practice is defined based on an outcome of at least 60% residue cover and not as implementation of a specific management practice. Therefore, imperfect operation and maintenance of the practice is not a factor for performance.

Practice Limitations

- The HR BMP is defined as a stand-alone practice that can be implemented with other BMP's however the sediment reduction values represent only that achieved by the HR practice.
- The practice is limited to lo-till cropland.
- Ancillary benefits include, over time, increase soil organic matter, increased soil cation exchange capacity, increase water-holding capacity, and improved soil quality.
- Eliminating or minimizing tillage can result in surface application of fertilizer and manures with no, or very little, incorporation. The result could produce greater ammonia volatilization and soluble P losses in certain circumstances and management systems..

Modeling Considerations

- BMP Name: Continuous, High Residue, Minimum Soil Disturbance (HR)
- Acres: Number of acres under HR meeting the definition of 60% residue cover
- Location: Approved NEIEN geographies: County; County (CBWS Only); Hydrologic Unit Code (HUC12, HUC10, HUC8, HUC6, HUC4), State (CBWS Only)
- Date of Implementation: Year of HR implementation or continued management of an HR system
- See Attachment C
- Applicable verification standards:
  The HR BMP has been defined by the panel as an annual crop residue and tillage practice which will can be applied onto applicable Conservation Tillage BMP acres. Annual crop residue and tillage practices have subsequently been categorized by the Chesapeake Bay Program's Agriculture Workgroup as Single-Year Visual Assessment BMPs. The panel recommends that the appropriate verification guidance associated with this category of BMPs be implemented by the partnership in the verification of acres reported under this BMP.

- Panel comments on verification protocols recommended by the Verification Panel:
  The panel recommendations for defining, tracking and reporting to the Chesapeake Bay Program partnership models the HR BMP, is compatible with and supports the agricultural BMP verification guidance subsequent developed by the Agriculture Workgroup.

- Panel recommendations on what to use as default conditions or default benefits if not all information about a practice is reported or known:
  The panel recommendations for defining the HR BMP were developed from the baseline of the existing Conservation Tillage BMP and associated Phase 5.3.2 Modeling land uses. The default condition and benefits if not all information is known or reported on a subset of reported acreage would be as the baseline condition; i.e. represented as a Conservation Tillage BMP.

Practice Monitoring and Reporting

This practice could be tracked through field transect surveys (CTIC methodology), potentially through remote sensing and limited field transect surveys in the future, or through state or federal programs that collect information on high-residue, minimum disturbance practices. The current CTIC methodology would need to be revised to include a category specifically with >60% cover. The panel discussed the importance of obtaining complete information about implementation of this practice. Therefore, information about implementation obtained through programs needs to be supplemented with other information to report acres where farmers practice HR voluntarily. The panel recommends that residue cover requirement (including living or dead material) is evaluated in the period shortly after planting a new crop. The acres that meet these criteria should be tracked and reported annually. A re-evaluation of the estimates should be conducted as new data are available.

Data Gaps and Research Needs

If remote sensing of residue cover is adopted in the future as the technology improves to meet the partnership's verification expectations, additional research validation will likely be required and protocols for evaluation developed.

Additional small watershed scale studies of sediment and especially N and P losses from representative locations within the Bay watershed would provide highly valuable information.

Attachments

- Attachment A: Summary of literature included in sediment reduction estimate

- Attachment B: Summary of literature reviewed for P reduction estimate
- Attachment C: Technical Requirements for Entering the Continuous, High Residue, Minimum Soil Disturbance (HR) Practice into Scenario Builder and the Watershed Model
- Attachment D: Initial Expert Panel survey summary, conducted by Tetra Tech
- Attachment E: Expert Panel meeting minutes/notes/attendance

Attachment A: Summary of literature included in sediment reduction estimate

Summary of High Residue, minimum soil disturbance practice Sediment reduction efficiency							
Citation	Notes						
Verbree, D. A., S. W. Duiker, 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	Central PA, limestone derived soil (WD) and colluvium-derived soil (SWPD), Flow-weighted average soil loss over 3 1-hr rainfall events (planting, mid-season,after silage harvest), Flow-weighted solids load (g m-2 h-1)			Flow-weighted solids load (g m-2 h-1)			
				Chisel/disk	NT	NT effiiciency	
			Well-drained	10.8	1.1	-89.8%	
			Well-drained	27.7	2.1	-92.4%	
			SWPD	10.6	2	-81.1%	
			SWPD	8.36	1.9	-77.3%	
					AVG	-85.2%	
Shipitalo, M.J. and W.M.Edwards. 1998. Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. Soil Till. Res. 46(1): 1-12	Average soil loss (kg/ha) in corn year of corn/wheat/meadow/meadow rotation, Research on about 0.5 ha watersheds, 7-13% slopes,		14 yr/location data		12 yr/location data		
			Chisel plowed		No-till	NT efficiency	
			Sed loss		Sed loss		
			3585.5		1380.5	-61.5%	
Truman, C.C., J.N. Shaw and D.W. Reeves. 2005. Tillage effects on rainfall partitioning and sediment yield from an ultisol in central Alabama. Journal of Soil and Water Conservation 60: 89-98.	Coastal plain of AL, sandy soil 1% slope, Total sediment loss (g) over two 1-hour rainfall simulation events (50 mm/hr), used 1m2 small plots, took treatments w/o paratill, but with residue (incorporated in chisel, left on surface in NT,	Total sediment loss (g) over two 1-hour rainfall simulation events (50 mm/hr)					
			Chisel	NT	NT efficiency		
			235	20	-91%		
Benham, B., D. Vaughan, M. Laird, B. Ross and D. Peek. 2007. Surface Water Quality Impacts of Conservation Tillage Practices on Burley Tobacco Production Systems in Southwest Virginia. Water Air Soil Pollut 179: 159-166.	Speedwell sandy loam 1% slope, Alluvial soil, Strip till was 59% cover, NT 82%, Conventional was 5% cove,r Rainfall simulation on 2.1x7m plots at 50 mm/hr. average soil loss kg/ha of 6 runs reported	Conv	Strip till	NT	NT efficiency	efficiiency vs Conv	
			Soil Loss, kg/ha				
		320.8	115.2	73	-36.6%	-77.2%	
Eghball, B. and J.E. Gilley. 2001. Phosphorus risk assessment index evaluation using runoff measurements. J. Soil Water Cons. 56: 202-206.	Sharpsburg sicl NE 6-7% and Monona si IA 12%, Did not use trtmnts with hedges		Disked	NT			
			Soil Loss, kg/ha				
			16.5	2.5			
			7	2.7			
			10.7	4.1			
			11.7	4.1			
			14	1.1			
			7	2			
			9.8	0.6			
			8.4	1.1			
			7.1	1.1			
			10.2	0.9			
			1.66	0.58			
			2.78	0.77			
			2.15	0.73	NT efficiency		
		Average	8.383846154	1.71384615	-79.6%		

Citation	Notes						
Staver, KW. 2004. EFFICIENT	Staver (personal communication, based on figure 19 in report Staver 2004.						
UTILIZATION OF POULTRY	CT was chisel-disk rye cover crop NT planted in both tillage treatments from 1988-1998						
LITTER IN CASH GRAIN							
ROTATIONS. Final Report			CT	CT	CT	CT	
submitted to: Maryland Grain	date	precip.	runoff	residue nf	residue nf	residue nf	
Producers Utilization Board		(cm)	(cm)	(kg/ha)	(kg/ha)	(mg/l)	
Maryland Center for Agro-	May 1- April 30						
	85-86						
	86-87	94.02	9.84	131.8	131.8	133.9	
	87-88	85.3	11.04	631.7	631.7	572.0	
	88-89	74.36	3.18	326.3	326.3	1027.2	
	89-90	99.18	9.51	1795.3	1795.3	1887.6	
	90-91	117.24	16.63	1051.4	1051.4	632.3	
	91-92	106.54	15.54	2581.9		1661.1	
	92-93	86.8	9.78	210.1	210.1	214.7	
	93-94	108.68	20.34	231.5	231.5	113.8	
	94-95	112.79	28.52	377.1	377.1	132.2	
	95-96	85.25	6.38	108.1	108.1	169.5	
	96-97	106.86	15.88	343.4	343.4	216.2	
	97-98	124.62	28.55	442.0	442.0	154.8	
	98-99	114.03	26.37	391.5	391.5	148.5	
	99-00	75.46	4.16	526.5	526.5	1267.2	
	00-01	128.8	21.75	82.4	82.4	37.9	
	01-02	103.91	11.01	256.2	256.2	232.7	
	02-03	100.77	10.52	28.9	28.9	27.4	
	03-04	118.31	26.73	155.5	155.5	58.2	
		143.37	42.82	187.0	187.0	43.7	
					404.3		
	residue nf = Residue non-filterable,all the material collected on a GFC filter pad with average pore size of 1.4 microns.						
					NT		
			NT	NT	residue nf		
		precip.	runoff	residue nf	(mg/l)		
	date	(cm)	(cm)	(kg/ha)			
					204.7		
	85-86	94.02	12.08	247.2	298.2		
	86-87	85.3	11.15	332.4	164.7		
	87-88	74.36	3.85	63.5	96.4		
	88-89	99.18	10.06	96.9	89.7		
	89-90	117.24	23.11	207.3	150.8		
	90-91	106.54	16.31	246.0	41.8		
	91-92	86.8	8.86	37.0	40.2		
	92-93	108.68	17.12	68.8	27.6		
	93-94	112.79	27.55	75.9	42.7		
	94-95	85.25	4.96	21.2	49.2		
	95-96	106.86	15.76	77.5	29.9		
	96-97	124.62	28.02	83.9	43.0		
	97-98	114.03	23.71	101.9	803.4		
	98-99	75.46	3.76	302.0	36.4		
	99-00	128.8	17.02	61.9	172.2		
	00-01	103.91	10.49	180.6	68.9		
	01-02	100.77	8.09	55.8	28.5		
	02-03	118.31	24.20	68.9	49.2		
	03-04	143.37	33.37	164.1			
				131.2			
	NT efficiency						
	-67.5%						
Kleinman, P.A., A. Sharpley, L.	Used rainfall simulation at 75 mm/hr			Sediment loss (kg/ha)			
Saporito, A. Buda and R. Bryant.	intensity, until 30 minutes of runoff had			Rototill 20 cm	NT	NT efficiency	
2009. Application of manure to	finished.	Clymer sandy loam		69.2	36.2	-47.7%	
no-till soils: phosphorus losses		Wharton clay loam		166.3	119.3	-28.3%	
by sub-surface and surface					av	-38.0%	
pathways. Nutrient Cycling in							
Agroecosystems 84: 215-227.							
doi:10.1007/s10705-008-9238-3.							

Attachment B: Summary of literature reviewed for P reduction estimate

Summary of High Residue, minimum soil disturbance practice P reduction efficiency

Literature Citation	Particulate P	Dissolved P	Subsurface P	Total P	Location	Notes
	% change Conserv-Till to HRMSD (NT)					
Benham, B., D. Vaughan, M. Laird, B. Ross and D. Peek. 2007. Surface Water Quality Impacts of Conservation Tillage Practices on Burley Tobacco Production Systems in Southwest Virginia. Water Air Soil Pollut 179: 159-166. doi:10.1007/s11270-006-9221-z.				-23%	VA; Ridge and Valley	Rainfall simulation on 2.1x7m plots at 50 mm/hr. average soil loss kg/ha of 6 runs reported; Speedwell sandy loam, 1% slope; alluvial soil; No till was 82% cover, strip till was 59%, conventional till was 5%
Verbree, D. A., S. W. Duiker, 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	-73%	333%		-5%	PA	Central PA, limestone derived soil (WD) and colluvium-derived soil (SWPD). 3, 1-hr rainfall events (planting, mid-season,after silage harvest)
Kleinman, P.J.A., A.N. Sharpley, B.G. Moyer and G.F. Elwinger. 2002. Effect of Mineral and Manure Phosphorus Sources on Runoff Phosphorus. J. Environ. Qual. 31: 2026-2033. doi:10.2134/jeq2002.2026.				147%	PA	3 soils, 4 P sources, 100 kg/ha TP applied, rainfall sim
Andraski, B.J., D.H. Mueller and T.C. Daniel. 1985. Phosphorus Losses in Runoff As Affected by Tillage. Soil Sci. Soc. Am. J. 49: 1523-1527. doi:10.2136/sssaj1985.03615995004900060038x.		57%		-15%	Wisconsin, three locations, (silt loam soils)	Various STP due to previous treatments, small plot studies with NT vs Chisel, manure applied at est rate of 50 kg/ha of first-year available P. Rainfall simulation preplant and in September, results averaged
Bundy, L.G., T. W. Andraski, and J. M. Powell. 2001. Management practice effects on phosphorus losses in runoff in corn production system. J. Environ Qual. 30(5):1822-28		-60%		-35%	*no manure*	STP, tilage and manure treatments. Fig 4 DRP concentration and Loss. Fig 5 TotP concentration and loss. History of biosolids to generate various STP. Spring manure application, chisel plow (CP), shallow till (ST), and no-till (NT). Rainfall simulation preplant and in September, results averaged
		0%		-80%	*with manure*	
Kimmell, R.J., G.M. Pierzynski, K.A. Janssen and P.L Barnes. 2001. Effects of Tillage and Phosphorus Placement on Phosphorus Runoff Losses in a Grain Sorghum–Soybean Rotation Contribution no. 00-358-J from the Kansas Agric. Exp. Stn. J. Environ. Qual. 30: 1324-1330. doi:10.2134/jeq2001.3041324x.				-56%	Woodson sl, Ottawa KS 1.5% slope	ridge till vs NT, small plot, grain sorghum/soybean rotation, Fertilizer P, natural rainfall collected throughout two seasons (6-7 events/year)
Kleinman, P.A., A. Sharpley, L. Saporito, A. Buda and R. Bryant. 2009. Application of manure to no-till soils: phosphorus losses by sub-surface and surface pathways. Nutrient Cycling in Agroecosystems 84: 215-227. doi:10.1007/s10705-008-9238-3.	5%	80%	71%	10%	PA Plateau	Clymer and Wharton soil, manure application of 30 kg/ha TP, subwatershed, includes leachate

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Quincke, J.A., C.S. Wortmann, M. Mamo, T. Franti, R.A. Drijber and J.P. García. 2007. One-Time Tillage of No-Till Systems. Agron. J. 99: 1104-1110. doi:10.2134/agronj2006.0321.	14%	0%		9%	Nebraska, 2 and 3% slope	NE, sharpsburg scl, Yutan scl, corn soy sorghum rotation, NT since 1992one time tillage after 15 yr NT, disc vs NT, rainfall sim, 2 yr after tillage
Sharpley, A.N., S.J. Smith, J.R. Williams, O.R. Jones and G.A. Coleman. 1991. Water Quality Impacts Associated with Sorghum Culture in the Southern Plains. J. Environ. Qual. 20: 239-244. doi:10.2134/jeq1991.00472425002000010038x.				-32%	OK, TX	grain sorghum in southern plains, rainfall sim
Staver, KW. 2004. EFFICIENT UTILIZATION OF POULTRY LITTER IN CASH GRAIN ROTATIONS. Final Report submitted to: Maryland Grain Producers Utilization Board Maryland Center for Agro-Ecology, MCAE Pub. 2004-03	-65%	421%		238%	Coastal Plain	Wye REC, MD: 4-yr study. small watershed scale study. The primary objective of this project was to evaluate the effect of nitrogen-based poultry litter applications on phosphorus and nitrogen transport rates in tilled and no-till settings during a three crop/two year rotation of corn/wheat/double-crop soybeans. Two complete cycles of the rotation were completed. Poultry litter was applied in the spring (3 tons/acre) prior to corn planting and also in the fall (2 tons/acre) prior to wheat planning in 1998 and 2000. During the second year of the rotation, no additional poultry litter was applied but nutrient transport patterns were tracked during wheat/double-crop soybean production. To meet the project objectives poultry litter was applied to two fully instrumented field-scale watersheds where detailed studies have been conducted since 1984 of nutrient transport rates from cropping systems utilizing inorganic fertilizers. Field edge
Ross, B. B., Davis, P. H., and Heath, V. L. June 11, 2001. Water Quality Improvement Resulting from Continuous No-Tillage Practices. Final Report. Colonial Soil and Water Conservation District.				-87%	Coastal Plain	A rainfall simulator was used to demonstrate and evaluate the effectiveness, in terms of NPS pollution control, of various nutrient inputs, as well as corn pre-planting and post-harvest tillage operations in preparation for small grain planting. An average 85.9 mm (3.38 in.) of artificial rainfall was applied to ten runoff plots during three separate runs conducted over a two-day period. During the simulated rainfall events, runoff from the plots was measured and

APEL Runs

	Coastal Plain		Piedmont		Ridge and Valley		Plateau	
STP	H	VH	H	VH	H	VH	H	VH
% change CT to NT	**-48%**	**108%**	**-56%**	**-16%**	**-57%**	**-16%**	**-60%**	**-31%**