AGRICULTURAL BMP NUTRIENT REDUCTION EFFICIENCIES: CHESAPEAKE BAY WATERSHED MODEL BMPs

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TABLE OF CONTENTS

LIST OF TABLES

Page

INTRODUCTION

The purpose of this report is to review literature on nutrient reduction effectiveness of agricultural best management practices (BMPs). This work will provide Chesapeake Bay watershed modelers with some background information on the expected edge-of-field efficiencies of the BMPs groups simulated by the model. The report is based on earlier studies on BMPs nutrient loads by North Carolina State University: Blalock (1987), Blalock and Smolen (1990); Interstate Commission on the Potomac River Basin (ICPRB): Casman (1989), Shirmohammadi and Shoemaker (1988); Crowder and Young (1985), Ross et al. (1987,1990), other field studies, and a recent report on BMP efficiencies by Casman (1990). The report provides BMP efficiencies for surface water, groundwater, and combined surface water and groundwater where possible.

The BMP nutrient reduction efficiency is defined as:

$$Efficiency(\%)=\left(1-\frac{post-BMP}{pre-BMP}\right)x100$$

where pre-BMP is the nutrient load before the BMP is installed or base case, and post-BMP is the load after BMP installation. From this equation it is observed that if the post-BMP load is greater than the pre-BMP load a negative efficiency is obtained which means an increase in nutrients instead of a reduction. Although this report focuses on nutrient reduction, soil loss and surface runoff reduction efficiencies are also provided.

The efficiencies are computed at the edge-of-field, or structure outlet for surface waters. For groundwater, the efficiencies are computed based on the nutrients that are leached out of the root zone (i.e. not available for plant uptake). Due to the fact that BMP efficiencies are site specific, the reported efficiencies in this document are documented as well as possible for the different hydrologic conditions, soil, slope, crops, and fertilization levels which characterize each particular study. Also, references to the procedures used and simulation or sampling time for each study addressed are provided. This documentation is very important for the use and interpretation of the results of each study. The studies reported are classified according to the BMP groups being considered for modeling in the Chesapeake Bay watershed model.

BACKGROUND

Many recognize nonpoint source pollution to be a significant factor affecting the water quality of the Chesapeake Bay. Chesapeake Bay states have been implementing nonpoint source programs in order to lessen the adverse environmental impact of present land use as well as land use changes within the basin. These programs have focused on improving the water quality of the tributaries draining into the Bay and therefore reducing the amount of nutrients entering the Bay. The different programs have been carried out with the implementation of best management practices (BMPs) for agricultural, urban and forest land uses. In the Chesapeake Bay, the contribution of nutrient loads from agriculture is large compared to urban and forest (about 57% of nitrogen and 54% of phosphorus of the total point and nonpoint source nutrient load into the Bay). On the other hand, urban nonpoint source nutrient loads are about 9% for nitrogen and phosphorus and forest loads are about 14% for nitrogen and 5% for phosphorus (Chesapeake Bay Program, 1990).

Chesapeake Bay Agricultural BMPs:

Traditionally, agricultural BMPs have been implemented to control erosion from farmland and consequently the transport of sediment-bound pollutants. However, lately, nonpoint source pollution programs are also focusing on implementation of agricultural BMPs that reduce the amount of dissolved nutrients entering a stream via surface water and groundwater. In particular, nutrient management programs are being developed by the states in order to help farmers effectively manage the nutrient application rates, timing, and methods according to the crop nutrient requirements. These programs contribute to the reduction of nutrient inputs into the land while maintaining or improving crop productivity.

Table 1 shows a summary of the agricultural BMPs in the Chesapeake Bay basin for Maryland, Pennsylvania and Virginia. The BMP classification and cross reference codes were developed by the Nutrient Reduction Task Force (NRTF) of the nonpoint source subcommittee. Similarly, Table 2 shows a classification of these BMPs by groups currently under analysis in the Chesapeake Bay watershed model.

Agricultural BMP Effectiveness:

Information on BMP effectiveness for the quantitative assessment of nutrient removal within the Chesapeake Bay is limited. Although there have been some field studies that

Table 1. State Agricultural BMP Cross Reference

BMP	Maryland Code	Pennsylvania Code	Virginia Code
Cropland Protection			
In Field:			
Stripcropping	SL-3	BMP-3	SL-3
Buffer Stripcropping			SL-3B
Terrace System	SL-4	BMP-4	SL-4
Sod Waterways	WP-3	BMP-7	WP-3
Protective Cover for Specialty crops	SL-8	BMP-8	SL-8
No-till Cropland	SL-15	BMP-9	SL-15
Legume Cover Crop			WQ-4
Contour Farming	SL-13		
Minimum-till Cropland	SL-14	BMP-9	
Field Wind Breaks	SL-7		
Edge of Field:			
Diversions	SL-5	BMP-5	SL-5
Sediment retention, Erosion, or Water Control Structures	WP-1 WC-1	BMP-12	WP-1
Grass Filter Strips	SL-11		WQ-1 WQ-2
Water Control Structures			WQ-5
Woodland Buffer Filter Area			FR-3
Pasture/Grazing Land Protection			
No-till Pasture and Hayland			SL-1
Grazing land Protection	SCS382	BMP-6	SL-6
Intensive Rotational Grazing Systems			WQ-3
Spring Development, Trough/Tank.	SL-6		
Stream Protection			
Stream bank Protection	WP-2	BMP-10	WP-2
Vegetative Stabilization of Marsh Fringe Areas			SE-1
Nutrient Management (NM)			
Small Grain Cover Crop for NM			SL-8B
Animal Waste Control Structure	WP-4	BMP-2	WP-4
Soil and Manure Analysis	SCS680	BMP-13	NMP
Transport of Excess Manure		BMP-14	NMP
Fertilizer Management	SCS680	BMP-15	NMP
Land Conversion			
Permanent Vegetative Cover of Critical Areas	SL-11	BMP-1 BMP-11	SL-11
Reforestation of Erodible Crop and Pastureland	SL-11		FR-1
Conservation Reserve Program	CRP	CRP	CRP
Forest Land Protection			
Woodland Erosion Stabilization			FR-4

Table 2. State BMPs Within Pervious Land Segments (PLS). Watershed Model (Phase II)

BMP	Maryland	Pennsylvania	Virginia
1-Conventional Tillage			
2-Conservation Tillage			
No-till Cropland	SL-15	BMP-9	SL-15
Minimum-till Cropland	SL-14	BMP-9	
3-Conventional Tillage with NM			
Fertilizer Management	SCS680	BMP-15	NMP
Nutrient Management Plans	SCS680		
Soil and Manure Analysis	SCS680	BMP-13	NMP
Small Grain Cover Crop for NM			SL-8B
Legume Cover Crop			WQ-4
4-Conservation Tillage with NM			
Fertilizer Management	SCS680	BMP-15	NMP
Nutrient Management Plans	SCS680		
No-till Cropland	SL-15	BMP-9	SL-15
Minimum-till Cropland	SL-14	BMP-9	
Soil and Manure Analysis	SCS680	BMP-13	NMP
Small Grain Cover Crop for NM			SL-8B
Legume Cover Crop			WQ-4
5-Conventional Tillage with NM and FP			
6-Conservation Tillage with NM and FP			
PLS 3 or 4 BMPs, plus:			
Stripcropping	SL-3	BMP-3	SL-3
Buffer Stripcropping			SL-3B
Contour Farming	SL-13		
Terrace Systems	SL-4	BMP-4	SL-4
Sod Waterways	WP-3	BMP-7	WP-3
Diversions	SL-5	BMP-5	SL-5
Sediment retention, Erosion,	WP-1		
or Water Control Structures	WC-1	BMP-12	WP-1
Water Control Structure			WQ-5
Grass Filter Strips	SL-11		WQ-1
Protective Cover for Specialty Crops	SL-8	BMP-8	SL-8
Field Wind Breaks	SL-7		WQ-2
7-Highly Erodible Land[1]			
8-Hayland			
9-Pasture		BMP-1	
Permanent Veg. Cover on Critical Areas	SL-11	BMP-11	SL-11
Conservation Reserve Program	CRP	CRP	CRP
10-Forest			
Woodland Buffer Filter Area			FR-3
Reforestation of Erodible Crop&Pastureland	SL-11		FR-1
Conservation Reserve Program	CRP	CRP	CRP
11-Manure Acres			
Animal Waste Control Structure	WP-4	BMP-2	WP-4
Transport of Excess Manure		BMP-14	NMP

NM = Nutrient Management
FP = Farm Plan
CRP = Conservation Reserve Program

1. Highly Erodible Land includes PLS 1-6 with high slopes and soil erodability. CRP and all BMPs are targeted here. CRP converted from here to pasture or forest.

directly or indirectly address the issue of BMP effectiveness within the Chesapeake Bay basin, the scope of these studies are still very limited, and can not be generalized to characterize the effectiveness of BMPs for the entire Chesapeake Bay basin.

BMP effectiveness is dependent on complex and site specific factors such as soils, slopes, crops, meteorology, and farmer diligence. Therefore, existing summaries on BMP efficiency studies tend to report ranges of effectiveness which can be quite broad. Also, the majority of the studies have concentrated their efforts on monitoring nutrients in surface waters while neglecting the groundwater. Some BMPs may be very effective in reducing nutrients in surface waters but they may increase the nutrient loading in groundwater.

It is important to understand that the efficiencies may be given for individual BMPs or for a combination of BMPs. The efficiencies may be given at the edge-of-field as in field test plots, or at some point away from the field at the outlet of a small or large watershed. However, it is important to note that as the distance between the downstream point and the field increases (i.e. watershed size increases), it becomes very difficult to isolate the effectiveness of the particular BMP or group of BMPs in the field. Nutrients leaving the field undergo biological and chemical transformations. Moreover, nutrients measured at remote sites may be combined with others coming from sources such as point sources, or nutrients returning from the subsurface into the stream confounding surface and subsurface efficiencies.

To address the issue of edge-of-the field effectiveness, many rainfall simulator studies have been conducted on small fields (plots) to evaluate individual BMP effectiveness. The main advantages of these studies are that the hydrologic conditions may be controlled and due to the homogeneity of the soil, slope, shape, and crops, BMP effectiveness may be characterized without site variability error. In addition, precise measurements of the nutrient loads from the pre-BMP and post-BMP conditions may be achieved for the evaluation of BMP effectiveness. The major drawbacks or limitations are that artificial rainfall event efficiencies may not translate into annual or long term efficiencies. Moreover, rainfall simulator studies on field plots do not account for potential high flow concentrations that may occur in larger fields.

In summary, edge-of-field efficiencies fall short of quantitatively addressing the issue of how effective a particular BMP is in improving the water quality of the receiving waters downstream from the field. Among the major issues that have not been completely resolved, and that are the cause of most of the on-going research on BMP effectiveness, the following are noted: There are many uncertainties concerning how long it takes for the receiving waters to react to the implementation of the BMP at different points downstream of the field, and on how effective a BMP is when combined with other BMPs. Little is known on how a reduction of fertilizer and manure applications is translated into a reduction of nutrients in surface water, groundwater, or at some point in the receiving waters downstream from the field, and what the system response time is to this reduction. Also, better understanding is needed on how to quantify the amount of the input nutrient loads that are lost by volatilization, denitrification, and crop uptake, the proportions that undergo mineralization and immobilization, and the role of atmospheric deposition.

Answers to these complex questions are likely to be site specific and may be partially obtained from studies on field plots, and small or large watersheds, and mathematical modeling. Recently, the manual prepared by R.E. Wright Associates, Inc. (1990) under contract by the Pennsylvania Department of Environmental Resources, attempts to answer some of these questions. The manual uses a mass balance approach to estimate the effects of nutrient management in agricultural fields with regard to the quality of surface water and groundwater. However, the estimates should be considered as best estimates of potential impacts which have not been fully tested or verified in the field.

BMP EFFICIENCIES

The efficiencies in this report are calculated according to the equation given in the introduction. For all the BMP groups considered, the efficiencies are computed (unless indicated) relative to the pre-BMP condition or base case of conventional tillage. The BMP groups analyzed in this report are:

Conservation Tillage
Conventional Tillage with Nutrient Management
Conservation Tillage with Nutrient Management
Conventional Tillage with Nutrient Management and Farm Plan
Conservation Tillage with Nutrient Management and Farm Plan
Animal Waste Management

In addition, some studies on vegetated filters strips are presented. The tables in the Appendix summarize the computed efficiencies for each of the BMP groups. Each table of efficiencies is accompanied by a table, describing for each study, the investigator name and reference, the location of the watershed or field, its size, simulation or experiment length, soil type, average slope, fertilization level and farm activity, crops, event rainfall or annual average rainfall, and some specific notes or comments.

Conservation Tillage

Conservation tillage can be defined as tillage or planting systems leaving residue crop covering at least 30% of the soil after planting (Dillaha, 1990). Conservation tillage is one of the most commonly used BMPs to control nonpoint pollution. It reduces the amount of soil eroded and therefore the transport of sediment-bound pollutants, as well as the runoff volume. However, concentrations of dissolved and sediment-bound pollutants may increase in surface runoff (Dillaha, 1990) and dissolved nutrients may also leach into the groundwater.

Despite the number of studies on conservation tillage, the effectiveness of this BMP is influenced by meteorology, soil, slopes, crop type, timing of fertilizer, previous crop, planter style, orientation of the contour etc., making generalization difficult (Casman, 1990).

Tables A-1-A to A-1-C (pg. A-2 to A-10) in the Appendix show a compilation of some studies on conservation tillage. Table 3 shows some summary statistics of the no-till efficiencies found for total nitrogen and phosphorus in surface water and groundwater. The statistics are given for studies grouped into two classes: field and CREAMS modeling studies. Although field studies may be further divided into rainfall simulator studies on small field plots and small watershed studies, they are grouped together since there are only a few studies reported on small watersheds.

The summary statistics are only provided to give an idea of the variability of the results obtained from these studies. Therefore, since the studies only cover a limited number of physiographic conditions and parameters measured, the median or average efficiencies should not be used indiscriminately as predictors of conservation tillage edge-of-field nutrient reductions in the entire Chesapeake Bay basin. For instance, most of the CREAMS work presented has been done for physiographic regions in Pennsylvania, while most of the rainfall simulator studies have been carried out in Virginia, and the small watershed studies reported here have been carried out in Maryland. In summary, the use of efficiencies from individual studies should be examined carefully in order to make sure that these studies fairly represent the conditions to be modeled.

Some generalizations about conservation tillage can be made from this compilation:

1- Surface runoff is usually reduced by conservation tillage practices. However, Table A-1-A shows a few cases where runoff increases with conservation practices (Staver et al., 1988 and Ross et al., 1990). In Staver's study the increase in runoff was due to increased runoff in the no-till watersheds in two major events in the winter. In Ross et al. (1990) the increase in surface runoff was due to high initial moisture conditions in the tests on Orange County.

2- Soil loss is effectively reduced by conservation practices. Table 3 shows an interquartile range from 74% to 99% for all the no-till studies. Only one study (Ross et al., 1990) showed an increase in soil loss with conservation tillage. Again this was due to the increased runoff for this experiment as well as the recent disturbance of the disked plot.

3- Reduction in total nitrogen and phosphorus in surface waters varied from -22 to 96% for nitrogen and -151% to 97% for phosphorus. In general, negative efficiencies (increases in dissolved nutrients) are correlated to increases in runoff. In particular, Staver et al. (1988) noted that in well drained soils in the eastern shore of Maryland no-till practices

Table 3. No-Till: Reduction Efficiencies Summary Statistics

Parameter	Study	Number of Obvs.	Median (%)	Average (%)	Standard deviation (%)	Min. (%)	Max. (%)	Lower quartile (%)	Upper quartile (%)
Total Nitrogen Surface Water	Field	20	82	65	34	-22	96	51	88
	CREAMS	13	51	53	16	21	95	50	54
	All Studies	33	54	60	28	-22	96	50	86
Total Nitrogen Groundwater	Field	-	-	-	-	-	-	-	-
	CREAMS	13	18	8	15	-16	24	-8	20
	All Studies	13	18	8	15	-16	24	-8	20
Total Nitrogen Surface Water + Groundwater	Field	-	-	-	-	-	-	-	-
	CREAMS	13	37	31	15	5	54	25	38
	All Studies	13	37	31	15	5	54	25	38
Total Phosphorus Surface Water	Field	26	88	61	62	-151	97	54	91
	CREAMS	13	58	54	21	1	88	54	60
	All Studies	39	71	59	51	-151	97	54	90
Surface Runoff	Field	20	52	47	37	-28	93	27	78
	CREAMS	5	24	28	17	11	57	21	25
	All Studies	25	47	43	34	-28	93	21	75
Soil	Field	20	97	89	14	47	99	81	99
	CREAMS	7	74	74	15	46	97	69	84
	All Studies	27	90	85	16	46	99	74	99

increased the transport phosphorus in the surface waters. However, they concluded that the total transport of phosphorus may only be reduced for high rainfall years by no-till practices as soil losses are reduced.

4- Subsurface nitrate losses increase with conservation practices. Three out of four studies reported by Casman (1990) given in this table support this conclusion. Negative efficiencies were from -28 to -231 with only one study reporting a positive efficiency of 38. The CREAMS work by Shirmohammadi and Shoemaker (1988) also reported negative efficiencies between -6 and -16. However, Crowder and Young (1985) reported positive efficiencies only if conservation tillage was accompanied by reduced fertilization levels. This latter statement supports the widely accepted conclusion that conservation tillage nutrient reduction efficiencies may improve in conjunction with nutrient management.

In summary, only one field study reported efficiencies of 36% and 32% for total nitrogen and phosphorus in surface water and groundwater combined. The median combined efficiency of total nitrogen from the CREAMS studies was 37%. Therefore, it seems that an upper bound of expected efficiencies for conservation tillage may be around 32 to 37% for both nitrogen and phosphorus. Casman (1990) suggested a 35% annual efficiency as an upper bound, and noted the efficiencies can change dramatically between seasons.

Conventional Tillage with Nutrient Management

According to the Chesapeake Bay Nutrient Reduction Task Force:

> *"A nutrient management plan is a management practice which provides recommendations on optimum nutrient application rates, optimum nutrient application times, and optimum nutrient application methods based on soil and manure analysis results and expected crop yields."*

Selected studies on nutrient management alternatives have been included under this section. Tables A-2-A to A-2-C in the Appendix (pg. A-12 to A-17) show the computed efficiencies and descriptions of these studies. Three different nutrient management components are reported in the studies summarized: 1- nutrient application rates; 2- nutrient application methods; and 3- nutrient application time.

Nutrient Application Rates:

From the study by Whitaker et al., (1978) (Table A-2-C, pg. A-16), it is observed that fertilizer reductions improve the efficiencies for dissolved nitrogen in runoff. However, it is important to note that fertilizer reductions from the optimum are not a nutrient management BMP. Nevertheless, it is observed that over fertilization lowers the efficiencies. In the Conestoga Headwaters Rural Clean Water Program (RCWP) project, it was found that halving the nitrogen application (mostly from manure) resulted in approximately a 10% reduction in nitrogen in runoff in a field with terraces (Brown, 1990). From the CREAMS studies, improvements on efficiencies of two nutrient management alternatives (from -20% to 0%, and from -20 to 33%) for nitrates in groundwater are also observed as fertilizer inputs are reduced.

With regard to the percentage of applied fertilizer that is lost, Mostaghimi et al. (1988) reported an average loss of approximately 9% in runoff of the phosphorus applied for all the fertilizer treatments in their conventional till test plots. For the no-till plots the loss was about 1%. Casman (1990), from six studies reported a median 15% loss of applied nitrogen as groundwater nitrate, and found that in general the percent losses were independent of the applied fertilizer.

Nutrient Application Methods:

For the Mostaghimi et al. (1988) study, reductions of 45% in total phosphorus in surface waters were observed for subsurface injection relative to surface application. Efficiencies of 60% were obtained for no-fertilizer relative to surface application. However, no data for losses via groundwater were reported. Accounting for losses of nutrients to groundwater by subsurface injection of fertilizers may result in small efficiencies for nutrients in both surface water and groundwater. Casman (1990) reported a 50% reduction in total nitrogen and phosphorus in runoff due to subsurface banding (i.e. injecting the fertilizer several inches below the surface) from the studies of Whitaker et al. (1977), and Adraski et al. (1985).

Nutrient Application Time:

Runoff nutrient reduction efficiencies between 58% and 76% are obtained by application of recommended fertilizer levels in the spring instead of the fall (Reckhow et al., 1980). From Whitaker et al. (1978), a two year average 21% reduction in dissolved mineralized nitrogen is observed by application in the spring relative to the fall. In addition, Casman (1990) points out that particulate nitrogen losses as well as groundwater losses are the important factors to consider between spring versus fall application.

In summary, nutrient reduction efficiencies for spring fertilization are closely correlated to the amount of fertilizer level reduced, and depend on the actual levels of fertilization.

Conservation Tillage with Nutrient Management

Tables A-3-A to A-3-C in the Appendix (pg. A-19 to A-24) summarize the efficiencies for studies within this BMP group. With conservation tillage, the particulate nutrient losses are considerably reduced since soil losses are minimized. The CREAMS results show reduction efficiencies between 40% and 73% for particulate nutrients. Also, efficiencies in the upper 90s for the rainfall simulator studies by Mostaghimi et al. (1988) relative to efficiencies in the 50s for the same studies but on conventional tillage plots, show that for nutrients in surface waters, further reductions are achieved with conservation tillage.

Conventional Tillage with Nutrient Management and Farm Plan

Tables A-4-A to A-4-C in the Appendix (pg. A-26 to A-28) summarize the efficiencies for farm plans involving: 1- contour farming; 2- terraces with grassed waterways; and 3- stripcropping, diversions and grassed waterways. Only one field study was found for terraces and grassed waterways.

Contour Farming:

Comparing the CREAMS studies #19 to #22 in Table A-2-A (Conventional Tillage with Nutrient Management; pg.A-13) with the studies #7 to #10 in Table A-4-A (Conventional Tillage with Nutrient Management and Farm Plan; pg. A-26) it is observed that nutrient reduction efficiencies in surface water were improved from an average efficiency of 29% without contour farming to 49% with contour farming for total nitrogen, and from an average efficiency of 36% to 56% for total phosphorus. However, total nitrogen for the combined surface water and groundwater was only improved slightly from an average efficiency of 29% to 35%. For nitrates in groundwater the average efficiencies decreased from 31% to 27%. Soil loss efficiencies were improved considerably from 0% to an average efficiency of 40%. In general, contour farming is more effective in reducing soil loss for mild slopes (smaller than 8%) and permeable soils (North Carolina State University, 1982).

Terraces and Grassed Waterways:

An efficiency of 66% for total phosphorus in runoff is derived from the study of Langdale et al. (1985). From the CREAMS work of Shirmohammadi and Shoemaker (1988) the effects of terraces may be isolated by comparing studies # 20 and 22 from Table A-2-A (Conventional Tillage with Nutrient Management; pg. A-13) with the studies #2 and #3 of Table A-4-A (Conventional Tillage with Nutrient Management and Farm Plan; pg. A-26). From these studies it is observed that terraces improved the efficiencies of total nitrogen in runoff from 27% to 70%, and from 20% to 75%. For total phosphorus in surface water, the efficiencies improved from 52% to 83% and from 14% to 80%. The efficiencies for total nitrogen in surface water and groundwater combined only improved from 35% to 43% and from 35% to 40%. For nitrates in groundwater the efficiencies were decreased from 38% to 34% and from 55% to 23%. As expected, terraces, although effective in reducing nutrients in surface waters due to the reduction of the transport of sediment-bound nutrients, are not as effective in reducing nutrients in both surface and groundwater combined as shown by the decrease in efficiencies for groundwater nitrates. Despite the differences between the studies, it is interesting to note that the efficiencies for total phosphorus in surface waters obtained in the CREAMS studies are of the same order of magnitude as the 66% efficiency from Langdale's study.

Stripcropping, Diversion, and Grassed Waterways:

Stripcropping with diversions and grassed waterways has been found to significantly reduce soil losses (Shirmohammadi and Shoemaker, 1988) and consequently, the transport of sediment-bound pollutants. This reduction is shown in the improvement of the efficiencies when comparing study #21 in Table A-2-A (Conventional Tillage with Nutrient Management; pg. A-13) with #11 on Table A-4-A (Conventional Tillage with Nutrient Management and Farm Plan; pg. A-26). The results reported show an improvement from an efficiency in surface water of 20% to 82% for total nitrogen, and from 14% to 89% for total phosphorus. For total nitrogen in surface water and groundwater combined, the efficiency improved from 35% to 67% while for nitrates in groundwater the efficiency decreased from 55% to 48%.

In summary, and taking into account the limited amount of studies found, it can be concluded that implementation of farm plan components over conventional tillage with a nutrient management plan improves the total nitrogen efficiency in both surface water and groundwater combined by an average of +6 percentage points for contour farming, +7 for terraces, and +32 for stripcropping with diversions and grassed waterways. For total nitrogen in surface water, the efficiencies are improved by an average of +21 percentage points for contour farming, +49 for terraces, and by +62 for stripcropping with diversions and grassed waterways. For nitrates in groundwater the efficiencies are decreased by -4 percentage points for contour farming, -18 for terraces, and by -7 for stripcropping. For total phosphorus in surface waters the efficiencies are improved by an average of +19 percentage points for contour farming, +49 for terraces, and +75 for stripcropping with diversions and grassed waterways.

The average percentage point increases of all the farm plan BMPs over the conventional tillage with nutrient management efficiencies were: For total nitrogen in both surface water and groundwater combined, +15 percentage points; for total nitrogen in surface water, +44 percentage points; for nitrates in groundwater, there was an average decrease of -10 percentage points; and for total phosphorus, the increase was +51 percentage points.

Conservation Tillage with Nutrient Management and Farm Plan

Tables A-5-A to A-5-C in the Appendix (pg. A-31 to A-32) show results from studies of: 1- contour farming; 2- terraces, contour farming, stripcropping and grassed waterways and 3- filter strips. The study on filter strips was the only field study reported. This rainfall simulation study was reported by Ross et al. (1990) in Prince Edward County in Virginia. Although this particular study focused specifically on the evaluation of tillage practices, and all plots were equally fertilized, this study is included here because it was the only recent study found regarding the analysis of the combined effectiveness of a tillage practice and a farm plan component such as a filter strip.

<u>Contour Farming:</u>

The improvement of the efficiencies by adding contour farming to conservation tillage with nutrient management is small. The effects of contour farming can be isolated by comparing studies #1,#2 and #4 on Table A-5-A (Conservation Tillage with Nutrient

Management and Farm Plan; pg. A-30) with #11-13 on Table A-3-A (Conservation Tillage with Nutrient Management; pg. A-20). From these studies, it is observed that adding contour farming to a no-till with nutrient management slightly improved the efficiencies. For surface waters, the efficiencies for total nitrogen are improved from an average efficiency of 65% to 69%, for total phosphorus from an average efficiency of 75% without contour farming to 79%, and for total nitrogen in both surface water and groundwater combined from 34% without contour farming to 35%. The efficiencies decreased from an average of 16% to 15% for nitrates in groundwater. These improvements are not as high as the efficiencies gained by implementing contour farming for the conventional tillage with nutrient management plan. This is partially explained by the fact that the no-till BMP already is accounting for most of soil loss reductions and therefore the reductions on the transport of sediment-bound nutrients.

Terraces, Contour Farming, Stripcropping and Grassed Waterways:

In the CREAMS studies reported by Crowder and Young (1985) (see Tables A-5-A and A-3-A), it may not be possible to isolate the overall effects of the farm plan components. The efficiencies reported in Table A-5-A are based on a nutrient management plan with a 12 month manure storage and plowdown incorporation while the efficiencies for the studies in Table A-3-A are based on a nutrient management plan of 6 month manure storage with topdress application. Nevertheless, the average efficiencies improve for nutrients in surface waters, from an average of 59% to 76% for total nitrogen, and from an average of 67% to 85% for total phosphorus. For total nitrogen in both surface water and groundwater combined, the average efficiencies improved from 40% to 42%, and for nitrates in groundwater the average efficiencies decreased from 48% to -1%.

Filter Strips:

Ross et al. (1990), recently reported a rainfall simulator study on filter strips in Prince Edward County Virginia. At the lower end of one of the no-till plots (50'x 120'), a 20-foot wide section of cover crop was left undisturbed in order to simulate a no-till with filter strip BMP. For surface waters, the filter strip improved the efficiency (from the no-till to the no-till with a filter strip) from 88% to 91% for total nitrogen, and from 94% to 97% for total phosphorus. Also, major improvements in dissolved phosphorus in surface waters were observed as the efficiency improved from 38% to 80%. However, it is pointed out that studies in small field plots may not represent actual field conditions where flows passing through the filter may be concentrated. These concentrated flows may substantially decrease the nutrient reduction efficiency of the filter strip.

In summary, for this BMP group the added nutrient reduction efficiency is only slightly improved. For total nitrogen in both surface water and groundwater combined, the efficiencies are improved by an average of +1 percentage points for contour farming, and by +2 for stripcropping with terraces and grassed waterways. For total nitrogen in surface waters, the efficiencies were improved by +4 percentage points for contour farming, by +13 for stripcropping with terraces and grassed waterways, and +3 for filter strips. For total phosphorus in surface waters, the efficiencies are improved by an average of +4 percentage points for contour farming, +18 for stripcropping with terraces and grassed waterways, and +4 for filter strips. For nitrates in groundwater, the average efficiencies decreased by -2 percentage points for contour farming, while the efficiencies for the studies with terraces, stripcropping and grassed waterways, decreased by -17.

The average percentage point increases of all the farm plan BMPs over the conservation tillage with nutrient management efficiencies were: for total nitrogen in both surface water and groundwater, +2 percentage points; for total nitrogen in surface water, +7 percentage points. For total nitrogen in groundwater, there was an average decrease of -10 percentage points and for total phosphorus, there was an increase of +9 percentage points.

Animal Waste Management

Table A-6 (pg. A-34) summarizes some conceptual estimates by Casman (1990) for animal waste management. The main assumptions underlying these estimates are described on Table A-6; for details on the estimation procedures refer to the author's original document. In relation to the efficiencies given in Table A-6, it can be pointed out that these conceptual estimates may change according to changes in the manure losses given in the notes of the same table. Also, the efficiencies do not consider the application of fall manure into a cover crop. The given efficiencies should be used with caution since they have not been verified in the field. From this table, it is seen that the maximum efficiency achieved is 40% for both total nitrogen and phosphorus in both surface water and groundwater combined. The author also noted that a recent modeling study by Hession et al. (1989) reported an efficiency of approximately 45% for both total nitrogen and phosphorus due to the implementation of dairy farm BMPs in a small watershed in Virginia. This prediction was obtained through the Agricultural Nonpoint Source (AGNPS) water quality model simulation of this watershed assuming that the manure was 100% managed.

Vegetated Filter Strips and Grassed Waterways

Vegetated filter strips as described by Dillaha (1990) are "bands of planted or indigenous vegetation, situated between pollutant source areas and receiving waters, which remove sediment and other pollutants from surface runoff". Total nutrient removal from a filter strip may be accomplished by adsorption and absorption within the strip. Although this is a single BMP and is only one of the components of a farm plan according to the classification given in Table 2 (pg. 4), the studies in Table A-7 (pg. A-36) are included due to their significance.

Table A-7-A (pg. A-36) shows a wide range of efficiencies for vegetated filter strips. As reported in Casman (1990), the main reason for the wide range of efficiencies is mainly due to the different factors that affect the effectiveness of a filter strip. Among those factors the following are noted: slope, length of filter strip, flow depth over the filter strip, soil type, influent characteristics, maintenance, reduction over time of the soil's ability to trap phosphorus, clogging of the filter and runoff loading. Also, Casman (1990) points out that for the studies of Magette et al. (1987) and Schwer and Clausen (1985) there were some inconsistencies with respect to the measuring of the pre-BMP loads. Dillaha (1990) reports that in general, vegetated filter strips are very effective in trapping sediment and sediment-bound pollutants with efficiencies exceeding 50% and that vegetated filter strips with concentrated flow were found to be 20-50% less effective than those plots under shallow flow. Dillaha (1990) also concluded that in hilly areas the vegetated filter strips are not effective in removing pollutants because in periods of heavy rainfall, which carry most of the pollutants, the flow tends to concentrate within the natural drainage pathways missing the filters. In flatter areas the filter strips were found to be more effective due to the uniformity of the slopes and the shallow flow passing over the filters. Adequate maintenance is required in order to maintain the efficiency of the filter strip.

In summary, the efficiency of a filter strip may vary depending on the aforementioned factors. Casman (1990), based on the studies by Dillaha and Magette reported in Table A-7-A, suggested 30% as an upper bound for the total nitrogen in both surface and groundwater combined that may be retained in a filter strip; for total phosphorus an efficiency range between 30% and 90% was observed. However, it is felt that the efficiencies obtained from these studies may be too high. They do not represent long term average filter strip efficiencies. The efficiencies of filter strips tend to decrease over time as sediment accumulates or as the filter strip deteriorate if not properly maintained. Furthermore, the study by Dillaha reported in Table A-7-A is for the treatment of feedlot runoff while the study by Magette is for cropland runoff.

Grassed waterways are very useful in preventing gully erosion, but not very effective in removing pollutants. Casman (1990) suggested an efficiency from 0-15% for total phosphorus and 0-2% for total nitrogen, using grass nutrient uptake values from the studies by Schwer and Clausen for the treatment of milkhouse wastewater. In general, flow through waterways is concentrated and therefore nutrient removal efficiencies are very small. These efficiencies are dependent on the ability of the grasses to take up nutrients flowing through them and on the condition of the waterway.

SUMMARY AND CONCLUSIONS

About 150 sets of efficiencies, with up to 10 efficiencies for the different nutrient forms in each set, have been compiled from over 30 research studies. The results of this study have limited ability to accurately quantify edge-of-field BMP efficiencies for all the regions in the Chesapeake Bay basin. For instance, it is noted that most of the studies reported for farm plan BMP components are from CREAMS work in Pennsylvania. Other limitations of the studies for which efficiencies have been computed have been mentioned before and are also further described by Casman (1990).

The accuracy of the results from modeling studies (such as CREAMS or AGNPS) depends highly on the ability of the modelers to successfully represent BMP implementation by parameter changes in the model. Although the responses of the models may be in the correct direction, the magnitude of the responses to BMP implementation may not equal actual changes in the field, since the models are not calibrated with monitoring data. Therefore, the magnitude of the efficiencies, although qualitatively reasonable, may be underestimated or overestimated. Nevertheless, in the absence of field data, CREAMS and other mathematical models are very useful tools for the evaluation of different BMP scenarios under different physical conditions.

Despite the aforementioned limitations, the efficiencies obtained in this report confirm many of the expected nutrient reduction trends for the different BMP groups analyzed. In Table 3 some efficiency ranges for no-till practices were provided. These efficiencies should not be used indiscriminately for predictions of nutrient reductions in all the physiographic regions of the Chesapeake Bay basin. Modelers should consult the tables in the Appendix, and the assumptions behind each particular study to make sure that they represent similar conditions to those being modeled. Also, efficiencies may change during the seasons of the year. Therefore, the tables in the Appendix should be consulted in order to verify that the given efficiencies are either long term averages or for a specific month or season.

In addition to the no-till efficiency ranges, the addition of farm plan components to conventional and conservation tillage with nutrient management was examined. Some average percentage increases in the efficiencies were computed for selected BMP groups of a farm plan. This analysis was performed to give modelers some rough estimates of expected improvements in the efficiencies due to the implementation of farm plan components. However, these percentage point increments can not be generalized because they were derived from very few sources. Moreover, they may be only valid for the ranges of efficiencies from which they were derived.

Finally, it is pointed out that the most important factor for determining the nutrient reductions due to the implementation of BMPs with nutrient management is the fraction of fertilizer reduction that can be translated into reductions of nutrients in surface water and groundwater. This factor may change according to how close the actual level of fertilizer applied is to the optimum. It depends on the fraction of the nutrients applied by fertilization that are taken up by the crops, the losses of nutrients by volatilization and denitrification and the extent of immobilization or mineralization of nutrients within the soil. Consequently, this fraction may change during the year. It may be different for each nutrient form in surface water or groundwater and under different BMPs.

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APPENDIX

Notation:

Runoff =	Surface Runoff
TN =	Total Nitrogen
TP =	Total Phosphorus
Soil =	Soil Loss
NH4 =	Ammonium
NO3 =	Nitrate
TKN =	Total Kjeldahl Nitrogen
PO4 =	Orthophosphate
D-PO4 =	Dissolved Orthophosphate
D-P =	Dissolved Total Phosphorus
Par-P =	Total Particulate Phosphorus
D-N =	Dissolved Total Nitrogen
Par N =	Total Particulate Nitrogen
D-NH4 =	Dissolved Ammonium
D-NO3 =	Dissolve Nitrate
D-TKN =	Dissolved Total Kjeldahl Nitrogen
CREAMS =	Chemical, Runoff, and Erosion from Agricultural Management Systems (a field scale model)
A -->>B =	Efficiency calculated from BMP "B" nutrient load (post-BMP) relative to BMP "A" nutrient load (pre-BMP or base case)

CONVENTIONAL TILLAGE --> > CONSERVATION TILLAGE

Table A-1-A. Conservation Tillage: Reduction Efficiencies[1]

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
1	Conv. Till --> > No Till	Angle et al. 1984	81	87/?/?	90/?/?	87	93/?	87/?	?	22/?	?	13/?	?	?	?	?	?	?
2	Conv. Till --> > No Till	Staver et al. 1988	-4	1/?/?	-25/?/?	47	?	?/11	?	-42/?	?	-47/?	2/?	7/?	?	?	?	?
3	Conv. Till --> > No Till		-22	-22/?/?	-104/?/?	80	?	?/8	?	-286/?	?	-291/?	58/?	8/?	?	?	?	?
4	Conv. Till --> > No Till	Ross et al. 1987 Rainfall Simulator	76	83/?/?	88/?/?	98	62/?	70/?	85/?	?	?	72/?	?	?	?	?	?	57/?
5			53	80/?/?	92/?/?	99	89/?	63/?	80/?	?	?	45/?	?	?	?	?	?	66/?
6			13	39/?/?	79/?/?	92	-166	43/?	39/?	?	?	-61/?	?	?	?	?	?	-19/?
7			62	57/?/?	82/?/?	82	80/?	-674	70/?	-68/?	?	89/?	?	?	?	?	?	53/?
8			75	88/?/?	97/?/?	99	66/?	29/?	92/?	-291	?	55/?	?	?	?	?	?	74/?
9	Conv. Till --> > No Till	Va Tech/DSWC 1989 Rainfall Simulator	41	68/?/?	35/?/?	96	?	?	?	?	?	?	?	?	?	?	?	?
10			62	15/?/?	87/?/?	98	?	?	?	?	?	?	?	?	?	?	?	?
11			42	52/?/?	53/?/?	90	?	?	?	?	?	?	?	?	?	?	?	?
12			47	84/?/?	90/?/?	99	?	?	?	?	?	?	?	?	?	?	?	?
13			87	96/?/?	96/?/?	99	?	?	?	?	?	?	?	?	?	?	?	?
14			41	86/?/?	90/?/?	99	?	?	?	?	?	?	?	?	?	?	?	?
15			85	94/?/?	94/?/?	99	?	?	?	?	?	?	?	?	?	?	?	?
16	Conv. Till --> > No Till	Ross et al. 1990 Rainfall Simulator	79	88/?/?	94/?/?	99	81/?	95/?	87/?	51/?	?	38/?	?	?	?	?	?	85/?
17			93	91/?/?	96/?/?	99	71/?	92/?	91/?	28/?	?	84/?	?	?	?	?	?	86/?
18	Conv. Till --> > Min Till		95	95/?/?	97/?/?	96	94/?	98/?	94/?	92/?	?	97/?	?	?	?	?	?	89/?
19	Conv. Till --> > Disced		-31	-182/?/?	-204/?/?	-41	-121/?	67/?	-295/?	-65/?	?	-83/?	?	?	?	?	?	-226/?
20			-43	4/?/?	1.5/?/?	-2.9	-38/?	-31/?	9.5/?	-91/?	?	9.3/?	?	?	?	?	?	-76/?
21	Conv. Till --> > Undistu.		-11	13/?/?	25/?/?	78	-37/?	-22/?	29/?	-186/?	?	-13/?	?	?	?	?	?	26/?
22			-33	39/?/?	26/?/?	90	-60/?	65/?	36/?	-264/?	?	-37/?	?	?	?	?	?	-124/?
23	Conv. Till --> > No Till	Alberts & Spomer 1985	?	?	?	?	?	?	?	?	-150/0	?	?	?	?	-39/-5	-55/ -231	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies Given for Surface Waters.

Table A-1-A. Conservation Tillage: Reduction Efficiencies[1] (cont.)

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	N03 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N %	D-NH4 %	D-NO3 %	D-TKN %
24	Conv. Till --> >No Till	House et al. 1984	?	?/?/?	?/20/?	?	?	?	?	?	?	?	?	?	?	?	?	?
25	Conv. Till --> >Min. Till	Ellis et al. 1985	40	33/36/36	50/-7/32	70	?	20/38/35	49/-4	?	?	43/-15	?	?	?	?	?	?
26	Conv. Till--> >No Till	Kanwar et al. 1987	?	?	?	?	?	?/-30	?	?	?	?	?	?	?	?	?	?
27	Conv. Till --> >No Till	Kitur et al. 1984	?	0	?	?	?	?	?	?	?	?	?	?	?	?	?	?
28	Conv. Till --> >No Till	Tyler & Thomas 1977	?	?	?	?	?	?/-28	?	?	?	?	?	?	?	?	?	?
29	Conv. Till--> No Till	Laflen & Tabatabi 1984	-28	49/?/?	50/?/?	66	?	?	?	?	-889	?	55/?	?	56/?	-700	-670	?
30			-3	68/?/?	70/?/?	75	?	?	?	?	-467	?	70/?	?	69/?	-786	-524	?
31	Conv. Till --> > Chisel		5	40/?/?	37/?/?	47	?	?	?	?	-122	?	37/?	?	40/?	-217	0	?
32			-3	26/?/?	29/?/?	32	?	?	?	?	-98	?	29/?	?	26/?	-158	-157	?
33	Conv. Till -> No Till	Adraski 1985	?	?	71/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
34			?	?	91/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
35			?	?	89/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
36			?	?	88/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
37	Conv. Till --> > No Till	Beaulac&Reckhow '82	50	89/?/?	85/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
38	Conv. Till --> > No Till	Mueller et al. 1984	?	?	54/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
39	Conv. Till --> > Chisel		?	?	33/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
40	Conv. Till --> > No Till		?	?	-151	?	?	?	?	?	?	?	?	?	?	?	?	?
41	Conv. Till --> > Chisel		?	?	83/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Waters

Table A-1-A. Conservation Tillage: Reduction Efficiencies[1] (cont.)

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	N03 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N %	D-NH4 %	D-NO3 %	D-TKN %
42	Conv. Till-- > > Min. Till	Blalock&Smolen 1990	44	45-59	44-70/?	67	?	?	?	?	?	?	?	?	?	?	?	?
43			27	32-41	38-60/?	55-61	?	?	?	?	?	?	?	?	?	?	?	?
44			24	31-38	36-41/?	49-56	?	?	?	?	?	?	?	?	?	?	?	?
45			21	28-38	33-43/?	46-54	?	?	?	?	?	?	?	?	?	?	?	?
46			20	31-39	36-44/?	53-57	?	?	?	?	?	?	?	?	?	?	?	?
47			29	39-44	42-47/?	56-59	?	?	?	?	?	?	?	?	?	?	?	?
48	Conv. Till -- > > No Till	Shirmohammadi & Shoemaker 1988	11	21/-6/6	23/?/?	46	?	?/-6	?	?	?	1/?	40/?	11/?	40/?	?	?	?
49			25	54/-8/9	54/?/?	74	?	?/-8	?	?	?	43/?	68/?	40/?	68/?	?	?	?
50			21	52/-8/25	58/?/?	74	?	?/-8	?	?	?	5/?	68/?	11/?	68/?	?	?	?
51			24	50/-16/5	54/?/?	69	?	?/-16	?	?	?	39/?	64/?	40/?	64/?	?	?	?
52	Conv. Till-- > > Min. Till	DelVecchio & Knisel 1982	57	95/-10/54	88/?/?	97	?	?/-10	?	?	?	?	?	?	?	?	?	?
53	Conv. Till -- > > No Till	Crowder & Young 1985	?	48/24/35	64/?/?	86	?	?/24	?	?	?	-363/?	80/?	-73/?	80/?	?	?	?
54			?	51/19/37	60/?/?	81	?	?/19	?	?	?	-99/?	72/?	-31/?	72/?	?	?	?
55			?	49/18/36	55/?/?	72	?	?/18	?	?	?	-62/?	63/?	-13/?	63/?	?	?	?
56			?	54/22/38	66/?/?	80	?	?/22	?	?	?	-385/?	74/?	-61/?	22/?	?	?	?
57			?	52/20/38	58/?/?	75	?	?/20	?	?	?	-145/?	66/?	-34/?	66/?	?	?	?
58			?	50/20/38	54/?/?	68	?	?/20	?	?	?	-112/?	60/?	-22/?	60/?	?	?	?
59	Conv. Till -- > > No Till	Crowder & Young 1988	?	68/15/44	75/?/?	84	?	?/15	?	?	?	?	?	?	?	?	?	?
60	Conv. Till -- > > No Till		?	51/19/37	60/?/?	72	?	?/19	?	?	?	?	?	?	?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Waters

Table A-1-B. Conservation Tillage: BMP Descriptions

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in[1].
1	Conv.Till --> > No Till	Angle et al. 1984 Paired Watersheds	Howard Co. MD	0.91/0.64	1980-82	Manor loam(coarse loamy)	6/7	Applied in June :4.02 g/m2 N(30% liquid) & 44.8 g/m2 6-24-24 dry fertilizer (N-P-K)	Corn	0.4-2.0[2]
2	Conv. Till --> >No Till	Staver et al. 1988 Paired Watersheds	Queen Annes Co. Eastern Shore MD	14.8/22	1986-1987	Matapex (silty) moderately well-drained	0-3	30lb/ac ammonium-nitrate-urea sol. at planting. 110lb/ac N (30% sol ammonium-nitrate) 30-50 days after planting. P in solution with N at 26lb/ac.	Corn	32(a)
3					1987-88					26(a)
4	Conv. Till --> > No Till	Ross et al. 1987 Rainfall Simulator	Southhampton Co. VA	1.15	5/15-16/86	Golsboro fine sandy loam	2	Fertilization equal for all plots. Cover crop in the fall or early spring was used for both the no-till and conventional tillage plots.	Corn	4
5			Essex Co. VA	0.69	6/19-20/85	Slagle fine sandy loam	5		Soybeans	3.4
6			Suffolk City VA	0.13	7/27-28/85	Suffolk loamy sand	2		Soybeans	3.5
7			Richmond Co. VA	0.34	8/6-7/86	Tetotum fine sandy loam	7		Corn	3.6
8			Surry Co. VA	0.6	8/11-12/86	Caroline fine sandy loam	6		Soybeans	4
9	Conv. Till --> > No Till	Va Tech/DSWC 1989 Rainfall Simulator	Mecklenburg Co. VA	0.35	7/14-15/87	Appling coarse sandy loam	3		Soybeans	3
10			Accomack Co. VA	0.23	8/18-19/87	Bojac loamy sand	3		Soybeans	4.2
11			Fluvanna Co. VA	0.27	9/17-18/87	Tatum silt loam	6		Alfalfa	3.2
12			Halifax Co. VA	0.17	7/26-27/88	Turbeville fine sandy loam	6		Soybeans	2.6
13			New Kent Co. VA	0.28	8/9-10/88	Kempsville sandy loam	4		Soybeans	2.6
14			Appomattox Co. VA	0.17	8/15-18/88	Cullen clay loam	19		Corn	2.4
15			Fauquier Co. VA	0.11	8/25-26/88	Penn silt loam	7		Corn	2.4
16	Conv. Till --> > No Till	Ross et al. 1990 Rainfall Simulator	Prince Edward Co. VA	0.14	7/26-27/89	Appling fine sandy loam	4	5/89: plated millet & 50lb/ac N 7/89: planted corn	Corn	3.2
17			Prince George Co. VA	0.17	8/16-17/89	Pamunky loam	2	9/88: (36 N,60 P,120 K) (lb/ac) planted wheat; 4-7/89: 63lb.ac N 7/89: planted soybeans	soybeans	3.7
18	Conv. Till --> > Min Till		Prince George Co. VA	0.17	8/16-17/89	Pamunky loam	2			
19	Conv. Till --> > Disced		Orange Co. VA (I)	0.1	9/20-21/89	Davidson Silty Clay	9	3/17/89: planted oats 6/1/89: (100 N,100 P,100K) (lb/ac) 6/5/89: planted corn	Corn (post-harvest)	3.2
20			Orange Co. VA (II)		4/25-27/89					3.5
21	Conv. Till --> > Undisturbed		Orange Co. VA (I)		9/20-21/89					3.2
22			Orange Co. VA (II)		4/25-27/89					3.5
23	Conv. Till --> > No Till Paired Watersheds	Alberts & Spomer 1985	Southern Iowa	83/107	1974-1983	Deep Loess		Watershed 1 = 150lb/ac N, 32lb/ac P Watershed 2 = 150lb/ac N, 29lb/ac P	Corn	30.2(a)

1. Rainfall given for individual storm events unless specified as annual average (a).

2. Event rainfall range for the years sampled

Table A-1-B. Conservation Tillage: BMP Descriptions (cont.)

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in.[1]
24	Conv. Till -- > > No Till	House et al. 1984 rep.by Casman 1990	Southern Pied. Georgia			Hiwassee loam	< 3	crop rotation: 2yr sorghum and 2 yr soybeans	sorghum soybeans	
25	Conv. Till -- > > Min. Till	Ellis et al. 1985	Michigan	10	2	Londo Loam-poorly drained	1		corn	
26	Conv. Till -- > > No Till	Kanwar et al. 1987 reported by Casman 1990	Iowa	plot 5x5 ft	1984-1986	Clairon-Nicollet silt loam	2	175lb/ac N all plots and 2 plots of no-till with 3 applications of N during growing season (22lb/ac in May, 45lb/ac in June and 45lb/ac in October	corn	35(a)
27	Conv. Till -- > > No Till	Kitur et al. 1984 rep.by Casman 1990	Kentucky	plot	3	Maury fine silty		N depleted NH4NO3 N: 75 lb/ac and 150lb/ac	corn	
28	Conv. Till -- > > No Till	Tyler & Thomas 1977 reported by Casman, 1990	Lexington, Kentucky	plot	1972-1974	Maury silt loam		Nitrogen as NH4NO3 at planting 150lb/ac/yr. KCL chloride in 1973 at 353lb/ac. Corn planted in mid May, & harvested in late Sep 1973 and early Oct 1974	corn	
29	Conv. Till -- > > No Till	Laflen & Tabatabi 1984 Rainfall Simulator	Iowa	0.1	May-June	Clairon-fine loamy	5	Hand spread fertilizers applied the day before tillage and planting and 7 weeks before rainfall simulation. Soybeans: 23lb/ac N,33 lb/ac P;Corn = +101lb/ac urea		
30	Conv. Till -- > > Chisel									
31	Conv. Till -- > > No Till					Monoma- fine silty	11	Hand spread fertilizers applied the day before tillage and planting and 3 weeks before rainfall simulation. Soybeans: 23lb/ac N,33 lb/ac P;Corn = +101lb/ac urea		
32	Conv. Till -- > > Chisel									
33	Conv. Till -- > > No Till Rainfall Simulator	Adraski 1985	Wisconsin		Sep 1980	Griswold Silt Loam	2%	At planting: N-P2O5-K2O was banded 3-3.9 Ins beneath the surface. 1981,81,83:[6-10.6-20(6-24-24)] at 240,224,240 lb/ac. In 1982: [6-3.5-6.6(6-8-8)] at 670lb/ac. Ammonium nitrate side-dressed in late Jun or early July at 178 lb/ac in 1980,81,82 and 274 lb/ac in 1983.	corn	2.9
34					Jul 1981					2.9
35					Oct 1982					3.5
36					Jun 1983					5.35
37	Conv. Till -- > > No Till	Beaulac&Reckhow '82 reported by Casman, 1990				Silt Loam		26 lb/ac/yr P	soybeans 2 crop	57(a)
38	Conv. Till -- > > No Till	Mueller et al. 1984 reported by Casman, 1990		plot	5/6/7 '79	Dresden Silt Loam		2223lb/ac(10-26-26) June 111lb/acNH4NO3	corn	5.7
39	Conv. Till -- > > Chisel									5.7
40	Conv. Till -- > > No Till	Mueller et al. 1984 reported by Casman, 1990				Dresden Silt Loam		223lb/ac(10-26-26) 111lb/acNH4n03 on June - manure	corn	5.7
41	Conv. Till -- > > Chisel									5.7

1. Rainfall given for individual events unless specified as annual average (a)

Table A-1-B. Conservation Tillage: BMP Descriptions (cont.)

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in[1]
42	Conv. Till --> > Min Till	Blalock & Smolen 1990 CREAMS	Chesapeake Bay	35	1974-78	Galestown,Loamy Sand "A"	2-6	April (10-5-5) 150lb N/yr. Chisel plowing on April 15 disking on April 16, planting on April 20 and harvesting on October 1.	Corn	44(a)
43						Norfolk,Loamy Sand "B"	2-10			
44						Cecil, Sandy Loam"B"	2-10			
45						Cecil, Sandy Clay Loam"B"	2-10			
46						Cecil, SCL erod. phase	4-10			
47						Penn Loam, "C"	2-10			
48	Conv. Till --> > No Till	Shirmohammadi & Shoemaker 1988 CREAMS	Upper Potomac sub-basin F	5	1949-78	silty clay loam	8	Dairy and commercial. 7 yr rotation: 1 yr corn grain, 3yr corn silage, and 3 yrs of hay	corn hay	37(a)
49			Lower Susquehanna sub-basin A	4.9		silt loam	8	Dairy and commercial. 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
50			North Branch Susq. sub-basin E	5.4		sandy clay loam	10.5	Dairy and commercial. 7 yr rotation: 3 yr corn silage, and 4 yrs of hay.	corn hay	34(a)
51			Juniata Sub-basin C	6		silt loam	12	Dairy and commercial. 7 yr rotation: 2yr corn grain, 2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
52	Conv. Till-- > > Min. Till CREAMS	DelVecchio & Knisel 1982	Southern		1955-74	Tifton Loamy Sand			3yr rotation	-
53	Conv. Till -- > > No Till	Crowder & Young 1985 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	20 Tons/ac of manure (annual). Daily spreading every 1 to several days.	corn grain following alfalfa	37-47(a)
54									continuous corn grain	
55									corn grain following corn silage	
56									corn silage following alfalfa	
57									corn silage following corn grain	
58									continuous corn silage	
59	Conv. Till -- > > No Till	Crowder&Young 1988 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	20 Tons/ac of manure (annual). Daily spreading 1 to several days.	continuous corn	42(a)
60										

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-1-C. Conservation Tillage: BMP Notes

#	BMP	Investigator	Notes
1	Conv. Till --> >No Till	Angle et al. 1984 Paired watersheds	32 storm events between 1980 and 1982. Total rain from sampled events: 1980: 12.5in; 1981: 6.2in; 1982: 10in. Conv. till watershed was contour plowed, disc-harrowed before planting. Plating in April harvesting in October. Stalks mowed. Soil not tilled in the fall. No-Till watershed: the stalks were also mowed and a cover crop of barley was seeded.
2	Conv. Till --> >No Till	Staver et al. 1988 Paired watersheds	Surface runoff for the storm in were 4.2 and 4.4in for the 1986-87 and 1987-88 crop years respectively. Conv. tillage watershed with Chisel Plowing with disking and field cultivator Crop residue less than 10%. Planting in May and harvesting in September. Planting is used in the No-till watershed. Crop: continuous corn since 1984. Unconfined aquifer with depth varying 3-13ft below the surface. No Till practice increases Phosphorus transport in surface waters. Particulate P decreases but dissolved P increases. Nitrogen follows runoff.
3			
4	Conv. Till --> > No Till	Ross et al. 1987 Rainfall simulator	Rainfall simulator intensity at approximately 2.0 in/hour. Rainfall applied at three different periods during two days. The rainfall sequences are defined as (Ross et al, 1987): 1-. 1 hour "dry" run (R1); 24 hours after R1 a "wet" run (R2) is applied for 1/2 hrs. and 3.- After 1/2 hr from R3 the last sequence ("wet",R3) is applied for 1/2 hr. R1 "on the first day approximates an intense storm pattern which would be expected to occur in Virginia as frequently as every two years" (Va Tech/DSWC, 1989).
5			
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8			
9	Conv. Till --> > No Till	Va Tech. / DSWC 1989 Rainfall simulator	Same as Ross et al. 1987
10			
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16	Conv. Till --> > No Till	Ross et al. 1990 Rainfall Simulator	Crops planted 3-4 weeks preceding the tests. Therefore canopy is minimal. Fertilization applications identical. For the no-till, minimum till and conventional tillage a cover crop in the fall or early spring was planted for #s 16-18. Minimum-Till plots with soils disced before planting. Soil was turn plowed and disced before planting (to incorporate the surface cover into the soil) in the conventional tillage plots. Rainfall simulation sequences defined previously in Ross et al. 1987. Mean rainfall application intensity was 1.73 in/hr ranging from 1.56 to 1.91 in/hr. Water Quality examples collected in 3 to 12 min intervals. For post-harvest tillage practices (#s 19-22) efficiencies are computed relative to plowed ground at Orange Co. Magnitude of runoff increases for the disced and undisturbed plots greater in spring than in the fall due to higher initial soil moisture conditions during the fall demonstration.
17			
18	Conv. Till --> > Min. Till		
19	Conv. Till --> > Disced		
20			
21	Conv. Till --> > Undisturbed		
22			
23	Conv. Till --> > Till-plant	Alberts & Spomer 1985	Watershed 1: 80% of N applied by two spring applications of anhydrous ammonia. The remaining N an P was surface applied as ammonium nitrate and superphosphate in April. Conventionally tilled since 1964. Watershed 2: not fertilized until 1968. 80% of N applied in April as anhydrous ammonium.

Table A-1-C. Conservation Tillage: BMP Notes (cont.)

#	BMP	Investigator	Notes
24	Conv. Till -- > > No. Till	House et al. 1984	Rotation: 2yrs of sorghum and 2yrs of soybeans. 1980-1981. Rye grown as a winter cover.
25	Conv. Till -- > > Min. Till	Ellis et al. 1985	Conservation till field was chisel plowed (50-60% of soil covered by corn residue). For the conventional till field moldboard plow was used. Water samples obtained using an ISCO model 1680 sampler. Overland flow through an H-flume.
26	Conv. Till -- > > No Till	Kanwar et al. 1987	Two rains of 5 and 2.5ins (.9in/hr) were applied one day apart.
27	Conv. Till -- > > No Till	Kitur et al. 1984	Rye cover crop was planted by broadcast over-seeding in mid-Sep. for both plots. Moldboard plow and disking was used in the conventional till plot. Fertilizer appl. with a hand sprayer.
28	Conv. Till -- > > No Till	Tyler & Thomas 1977	Corn planted in mid May for both years. Plant population 29,040 stalks/ac. Four lysimeters were installed, and leachate collected in 20-liter jugs.
29	Conv. Till -- > > No Till	Laflen & Tabatabi 1984 Rainfall Simulator	Tillage treatments: Plow- spring moldboard plowing, two diskings, planting. Chisel- spring chisel plowing, shallow disking, planting. No-till- no tillage before or after planting. Granular fertilizers were hand spread. A rotating-boom rainfall simulator was used; application rate: 2.5in/hr on an area of 10x35ft. Percentage of soil covered and canopy were measured before rainfall. Sediment separated by filtration.
30	Conv. Till -- > > Chisel		
31	Conv. Till -- > > No Till		
32	Conv. Till -- > > Chisel		
33	Conv. Till -- > > No Till Rainfall Simulator	Adraski 1985	Corn residue was distributed by hand in spring 1980 before planting. Stalks chopped in late November leaving residues. Plowing on the conventional and chisel till plots done in spring 1980 and fall of the growing season. In the till-plant ridges were formed in early November. Rainfall applied for 1hr, and runoff collected in 1.35m2 areas in Sep 1980, June and July 1981, Oct 1982, and June and July of 1983. Corn plants cut before rainfall simulation.
34			
35			
36			
37	Conv. Till -- > > No Till	Beaulac&Reckhow '82	
38	Conv. Till -- > > No Till	Mueller et al. 1984	Runoff collected in May, July and September 1978, and in June and August 1979. Rainfall was applied for 1 hr at a rate of 5.7in/hr.
39	Conv. Till -- > > Chisel		
40	Conv. Till -- > > No Till		
41	Conv. Till -- > > Chisel		

Table A-1-C. Conservation Tillage: BMP Notes (cont.)

#	BMP	Investigator	Notes
42	Conv. Till --> > Min. Till	Blalock & Smolen 1990 CREAMS	Slope length: 120ft and with uniform profile. Length-to-width ratio of 3.8 (based on hydrologic maps). Daily rainfall option used data from 1974-78 provided by CBLO. Average monthly temperatures and solar radiation were used. Base scenario defined as: Conventional tillage field with up-and-down plowing and crop residue less than 30% at planting. Alternate scenario: Conservation tillage field with contour chisel plowing with crop residue greater than 30% at planting.
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48	Conv. Till --> > No Till	Shirmohammadi & Shoemaker 1988 CREAMS	Commercial fertilizer: Corn grain- 75lb/ac N, 24lb/ac P Incorporated (7in) on May 8. Corn Silage 20lb/ac N ad P Incorporated (2in) on May 17 and 50lb/ac N surface applied on June 22 Hay-(1st yr) 20lb/ac N, 17lb/ac P Incorporated (1in) on April 15 and years 2-3 17lb/ac P surface applied on June 10. Manure(dairy): (10-4-8 analysis--10Tons/ac/yr) Corn- 10lb/ac N, 3lb/ac P and 1.9Tons/ac of manure surface applied on Nov. 1, Dec 1, Jan 15, Mar 1 and Apr 20.
49			Commercial fertilizer: Corn grain- 50lb/ac N, 21lb/ac P incorporated (8in) on April 25,20lb/ac N ad P Incorporated (3in) on May 7 and 50lb/ac N surface applied on June 15 Soybeans- 20lb/ac N, 18lb/ac P incorporated (5in) on April 12. Alfalfa: 20lb/ac N, 26lb/ac P incorporated (3in) with only one application in the first year. Manure(dairy): (10-4-8 analysis--18Tons/ac/yr) 15lb/ac N, 5.2 lbs/ac P and 2.8Tons/ac of surfaced applied manure on Nov. 1, Dec 1, Jan 1, Feb 1 for corn, Mar 1 and Apr 1 for soybeans, and May 25, Jun 21, Jul 21, Aug 26, Sep 1, and Oct 21 for alfalfa.
50			Commercial fertilizer: Corn grain- 75lb/ac N, 24lb/ac P incorporated (2in) on May 1,45lb/ac N and 19.6lb/ac P incorporated (2in) on May 15. Hay- (1st yr) 60lb/ac N, 11lb/ac P surface applied on April 20. Hay(yr 2-4): 0lb/ac N, 35lb/ac P surface applied. Manure(dairy): (10-4-8 analysis--18Tons/ac/yr) 8.3lb/ac N, 3.1lb/ac P and 1.6Tons/ac of surfaced applied manure on Nov. 1, Dec 1, Jan 1, Feb 1 for corn, and May 25, Jun 21, Jul 21, Aug 26, Sep 1, and Oct 21 for hay.
51			Commercial fertilizer: Corn grain- 75lb/ac N, 33lb/ac P incorporated (4in) on May 10,20lb/ac N and 26lb/ac P surface applied on May 15. Hay- (1st yr) 60lb/ac N, 11lb/ac P incorporated (4in) on April 1. Hay(yr 2): 0lb/ac N, 16lb/ac P surface applied. Manure(dairy): (10-4-8 analysis--15Tons/ac/yr) 15lb/ac N, 5.2lb/ac P and 2.8Tons/ac of surfaced applied manure on Oct 25, Dec 1, Jan 15, Mar 1 and April 20 for corn, and May 21, Jun 21,Jul 21, Aug 26, Sep 1, and Oct 21 for hay.
52	Conv. Till--> > Min. Till CREAMS	DelVecchio & Knisel 1982	Major crops grown on the Tifton loamy sand are: Corn, soybeans and peanuts. Three year rotation of corn-soybeans-peanuts is common. Conv. Till: Fall moldboard 5 ins deep; spring disk 4 in deep,; two sweep cultivators 2 in deep. Conservation tillage: contour tillage with residue management; shred crop residue; chisel on contour 12 In deep.
53	Conv. Till --> > No Till	Crowder & Young 1985 CREAMS	Tillage practices, planting and other management practices equal for all 3 years. Duffield series are deep, well drained with high moisture holding capacity. Good internal drainage due to underlying limestone. Highly productive soil. Losses of NO3 are leached through the root zone and assumed to be delivered via groundwater . Therefore no return of subsurface flow is assumed into the streams. Sediment delivery from erosion In Lancaster county is approximately 20% (Crowder & Young, 1985) Winter cover modeled after harvest of corn silage. Rye was planted in late September producing residue of 2,000 lbs /ac. Corn and Hay residue management adequate so no winter cover was modeled for this case. N and P2O5 at minimum levels of crop requirements. Applications of these nutrients modeled from combined manure, commercial fertilizer and legumes. Commercial Fertilizer plowed under conventional tillage and surface applied for no-till. Crop requirements: Corn grain (120 bush) 120lb/ac N, and 30lb/ac P2O5; Corn Silage(20tons) 140lb/acN and 32lb/ac of P2O5; Alfalfa hay: Establishment year (2.9Tons) 20lbs/ac N and 20lbs/ac of P2O5, meadow:(4.4Tons) 20 lb/ac of P2O5; and Grass pasture (2.5 tons) 50lb/ac N and 50lb/ac of P2O5. Manure applications of daily spreading modeled just before planting and after harvesting. Also disposal in late fall and late winter were modeled. No field was manured more than 4 times a year.
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59	Conv. Till --> > No Till	Crowder & Young 1988 CREAMS	
60			

CONVENTIONAL TILLAGE -- > > CONVENTIONAL TILLAGE WITH NUTRIENT MANAGEMENT

Table A-2-A. Conventional Tillage with Nutrient Management: Reduction Efficiencies[1]

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	N03 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
1	Conv. Till- > > Conv. Till + Nutrient Management Fertilizer level Application Time	Reckhow et al. 1980 reported by Casman, 1990	?	58/?/? 72/?/?	62/?/? 76/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
2			?	15/?/?	-27/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
3			?	-17/?/? -2/?/?	-63/?/? -60/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
4			?	-155/?/?	-35/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
5			?	-314/?/?	-127/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
6	Conv. Till - > > Conv. Till + Nutrient Management Spring plow relative to fall plow conventional tillage	Whitaker et al. 1978 reported by Casman, 1990	?	?	?	?	?	?	?	?	?	?	?	82/?	?	?	?	?
7			?	?	?	?	?	?	?	?	?	?	?	-75/?	?	?	?	?
8			?	?	?	?	?	?	?	?	?	?	?	-83/?	?	?	?	?
9			?	?	?	?	?	?	?	?	?	?	?	-194/?	?	?	?	?
10			?	?	?	?	?	?	?	?	?	?	?	21/?	?	?	?	?
11	Conv. Till - > > Conv. Till + Nutrient Management Fertilizer application relative to optimum level	Whitaker et al. 1978 reported by Casman, 1990	?	?	?	?	?	?	?	?	?	?	?	25/?	?	?	?	?
12			?	?	?	?	?	?	?	?	?	?	?	15/?	?	?	?	?
13			?	?	?	?	?	?	?	?	?	?	?	23/?	?	?	?	?
14			?	?	?	?	?	?	?	?	?	?	?	0/?	?	?	?	?
15			?	?	?	?	?	?	?	?	?	?	?	-168/?	?	?	?	?
16			?	?	?	?	?	?	?	?	?	?	?	-138/?	?	?	?	?
17	Conv. Till - > > Conv. Till + Nutrient Management Subsurface injection relative to surface application	Mostaghimi et al. 1988 Rainfall Simulator	?	?	45/?/?	?	?	?	?	35/?	?	?	43/?	?	?	?	?	?
18	Conv. Till - > > Conv. Till + Nutrient Management No-fertilizer relative to surface application		?	?	60/?/?	?	?	?	?	53/?	?	?	60/?	?	?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Water.

Table A-2-A. Conventional Tillage with Nutrient Management: Reduction Efficiencies[1] (cont.)

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N %	D-NH4 %	D-NO3 %	D-TKN %
19	Conv. Till --> >Conv. Till +Nutrient Management. Fertilizer level Application method	Shirmohammadi & Shoemaker 1988 CREAMS	0	31/.3/15	40/?/?	0	?	?/.3	?	?	?	91/?	0/?	47/?	0/?	?	?	?
20			0	27/38/35	52/?/?	0	?	?/38	?	?	?	96/?	0/?	55/?	0/?	?	?	?
21			0	20/55/35	14/?/?	0	?	?/55	?	?	?	88/?	0/?	70/?	0/?	?	?	?
22			0	37/30/32	39/?/?	0	?	?/30	?	?	?	95/?	0/?	66/?	0/?	?	?	?
23	Conv. Till--> >Conv. Till +Nutrient Management. 6 months manure storage + plowdown incorporation relative to daily surface spreading	Crowder & Young 1985 CREAMS	?	8/-20/4	8/?/?	?	?	?/-20	?	?	?	80/?	0/?	35/?	0/?	?	?	?
24			?	6/-3/2	5/?/?	?	?	?/-3	?	?	?	70/?	0/?	29/?	0/?	?	?	?
25			?	5/0/2	4/?/?	?	?	?/0	?	?	?	61/?	0/?	20/?	0/?	?	?	?
26	Conv. Till --> >Conv. Till +Nutrient Management. Injection relative to plowdown incorporation	Crowder & Young 1985 CREAMS	?	-9/-20/-15	0/?/?	?	?	?/-20	?	?	?	-23/?	0/?	-52/?	0/?	?	?	?
27			?	-3/36/15	0/?/?	?	?	?/36	?	?	?	-14/?	0/?	-19/?	0/?	?	?	?
28			?	-1/33/14	0/?/?	?	?	?/33	?	?	?	-5/?	0/?	-5/?	0/?	?	?	?

1. X/Y/Z => Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y => Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z => Total Nutrient Reduction (Surface Water and Groundwater)
? => Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Water

Table A-2-B. Conventional Tillage with Nutrient Management: BMP Descriptions

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain In[1]
1	Conv. Till -> > Conv. Till + Nutrient Management Fertilizer level Application Time	Reckhow et al. 1980 reported by Casman, 1990		0.01	1970	silt loam		recommended: 91lb-N/ac., 39lb-P/ac., 77lb-K/ac.	corn	26-31(a)
2										
3										
4										
5										
6	Conv. Till --> > Conv. Till + Nutrient Management Spring plow relative to fall plow	Whitaker et al. 1978 reported by Casman, 1990	Central Missouri	0.02	Nov-Mar/73	Mexico silt loam slowly permeable clay subsoil beginning at a depth of 7 to 18 ins	3	Plow down = 108lb-N/ac, at planting 13lb-N/ac, side dress = 68-Nlb/ac. Total = 189-Nlb/ac	corn	38(a)
7					Apr-May/74					
8					June/74					
9					Jul-Oct/74					
10					1973-74					
11	Conv. Till --> > No Till + Nutrient Management Applied fertilizer relative to optimum level	Whitaker et al. 1978 reported by Casman, 1990	Central Missouri	0.02	1973-74	Mexico silt loam slowly permeable clay subsoil beginning at a depth of 7 to 18 ins	3	13 lb-N/ac	corn	38(a)
12								87 lb-N/ac		
13								175 lb-N/ac		
14								189 lb-N/ac (optimum level)		
15								223 lb-N/ac		
16								325 lb-N/ac		
17	Conv. Till -> > Conv. Till + Nutrient Management Subsurface injection relative to surface application	Mostaghimi et al. 1988	Virginia	0.025	1988	Groseclose silt loam	8-14	Granular P fertilizer applied at 41lb-P/ac. 24-48 hrs before rainfall simulation.		3.9
18	Conv. Till --> > Conv. Till + Nutrient Management Subsurface injection relative to no-fertilization									

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-2-B. Conventional Tillage with Nutrient Management: BMP Descriptions (cont.)

#	BMP	Investigator	Location	Size (ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in[1]
19	Conv. Till – > > Conv. Till + Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Upper Potomac sub-basin F	5	1949-78	silty clay loam	8	Dairy and commercial (see Table A-2-C,pg.A-17).7yr rotation: 1yr corn grain,3yr corn silage, 3yr of hay	corn hay	37(a)
20			Lower Susquehanna sub-basin A	4.9		silt loam	8	Dairy and commercial (see Table A-2-C, pg.A-17). 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
21			North Branch Susq. sub-basin E	5.4		sandy clay loam	10.5	Dairy and commercial (see Table A-2-C, pg.A-17). 7 yr rotation: 3 yr corn silage, and 4 yrs of hay.	corn hay	34(a)
22			Juniata Sub-basin C	6		silt loam	12	Dairy and commercial (see Table A-2-C, pg.A-17). 7yr rotation: 2yr corn grain,2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
23	Conv. Till -- > > Conv. Till + Nutrient Management. 6 months manure storage + plowdown incorporation relative to daily surface spreading	Crowder & Young 1985 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	40 tons/ac of manure. Without nutrient management manure is stored for a few days (daily surface spreading). With nutrient management manure is incorporated with a plow and stored for six months.	continuous corn grain	37-47(a)
24								20 tons/ac of manure. Without nutrient management manure is stored for a few days (daily surface spreading). With nutrient management manure is incorporated with a plow and stored for six months.		
25								10 tons/ac of manure. Without nutrient management manure is stored for a few days (daily surface spreading). With nutrient management manure is incorporated with a plow and stored for six months.		
26	Conv. Till -- > > Conv. Till + Nutrient Management. Injection relative to plowdown incorporation	Crowder & Young 1985 CREAMS						40 tons/ac of manure. Without nutrient management manure is incorporated with a plow. With nutrient management manure is injected. Manure is stored for 1 year in both cases.		
27								20 tons/ac of manure. Without nutrient management manure is incorporated with a plow. With nutrient management manure is injected. Manure is stored for 1 year in both cases.		
28								10 tons/ac of manure. Without nutrient management manure is incorporated with a plow. With nutrient management manure is injected. Manure is stored for 1 year in both cases.		

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-2-C. Conventional Tillage with Nutrient Management: BMP Notes

#	BMP	Investigator	Notes
1	Conv. Till -> > Conv. Till + Nutrient Management Fertilizer level Application Time	Reckhow et al. 1980 reported by Casman, 1990	Efficiency determined from recommended fertilization application in the spring relative to recommended winter application of N and P. Efficiencies for all #s 1 to 5 derived from median nutrient loads. Little documentation was found for these studies.
2			Efficiency determined from 80% of recommended fertilizer applied in the spring relative to the recommended fertilizer applied in the spring.
3			Efficiencies determined from no-fertilizer relative to recommended application in the spring.
4			Efficiency determined from contour conventional with half recommended N and P relative to recommended spring application of N and P.
5			Efficiencies determined from contour conventional with 260% and 160% of recommended N and P respectively relative to recommended spring application of N and P.
6	Conv. Till --> > Conv. Till + Nutrient Management Spring plow relative to fall plow	Whitaker et al. 1978 reported by Casman, 1990	Data was read from a histogram. Soluble nitrogen consists of NO3-N and NH4-N Conventional tillage is spring plowing with disking before planting. Plots farmed parallel to slope (size: 10.5 x 90 feet) Corn planted at final stand of 20,000 to 22,000 plants/ac in 30ins rows.
7			
8			
9			
10			
11	Conv. Till --> > Conv. Till + Nutrient Management Applied fertilizer relative to optimum level	Whitaker et al. 1978 reported by Casman, 1990	Data was read from a histogram. Soluble nitrogen consists of NO3-N and NH4-N Conventional tillage is spring plowing with disking before planting. Plots farmed parallel to slope (size: 10.5 x 90 feet) Corn planted at final stand of 20,000 to 22,000 plants/ac in 30ins rows. Fertilization level of 189lb-N/ac assumed as optimum. Precipitation supplied an additional 4.5 lb-N/ac
12			
13			
14			
15			
16			
17	Conv. Till -> > Conv. Till + Nutrient Management Subsurface injection relative to surface application	Mostaghimi et al. 1988	Rainfall sequence the same as in Table 3-C #s 4-8 Twelve experimental plots divided into no-till and conventional tillage. Conventional plots tilled 4-6 ins deep with rototiller following disking.
18	Conv. Till --> > Conv. Till + Nutrient Management Subsurface injection relative to no-fertilization		

Table A-2-C. Conventional Tillage: BMP Notes (cont.)

#	BMP	Investigator	Notes
19	Conv. Till --> > Conv. Till + Nutrient Management Fertilizer level Application method	Shirmohammadi & Shoemaker 1988 CREAMS	Commercial fertilizer: Corn grain- 80lb/ac N, 4.3lb/ac P incorporated (4in) on May 17. Corn Silage 125lb/ac N and 24lb/ac P incorporated (4in) on May 17. Hay-(1st yr) 20lb/ac N, 26lb/ac P incorporated (4in) on April 15 and years 2-3 30lb/ac P surface applied on April 15. Manure(dairy): (10Tons/ac/yr--10-4-8 analysis) in 3 applications (50%,30%,20%) for N availability representation (on corn only). Corn-10 tons/ac incorporated (9in) --> 25lb/ac N, 8lb/ac P on April 15, 15 lb/ac N on May 25 and 10 lb/ac N on June 26.
20			Commercial fertilizer: Corn grain- 13lb/ac N incorporated (3in) on May 7, Soybeans- none. Alfalfa: 20lb/ac N, 26lb/ac P incorporated (3in) with only one application in the first year on April 7. Manure(dairy): (18Tons/ac/yr--10-4-8 analysis) with 3 application rates (50%,30%,20%) for N availability representation in the model. Corn, 18tons/ac incorporated (8in)--> 45lb.ac N and 31lb/ac P on April 23, 27lb/ac N on June 11 and 18lb/ac N on July 11. Same amounts for soybeans in Nov 1, Dec 18 and Jan 8 respectively, for alfalfa 6tons/ac manure incorporated (8in)--> 30lb/ac N and 10lb/ac P applied on Jun 9, Jul 14, and Aug 24.
21			Commercial fertilizer: Corn grain- 20lb/ac N, 17lb/ac P incorporated (2in) on May 14, Hay- (1st yr) 19lb/ac P incorporated (8in) on April 4 and 20lb/ac N and 26lb/ac P incorporated (2in) on April 20. Hay(yr 2-4): 0lb/ac N, 35lb/ac P top dress. Manure(dairy): (23tons/ac--10-4-8 analysis) 3 applications (50%,30%,20%) on corn for N availability representation in the model, 23 ton/ac--> 57lb/ac N, 40lb/ac P incorporated (8ins) on May 1. and 34lb/ac N and 23lb/ac N on June 12 and July 12 respectively.
22			Commercial fertilizer: Corn grain- 5lb/ac N, 0lb/ac P incorporated (4in) on May 15; Corn silage 25lb/ac incorporated (4in) on May 15. Hay- (1st yr) 20lb/ac N, 26lb/ac P incorporated (4in) on April 5. Manure(dairy): (15tons/ac--10-4-8 analysis) 3 applications (50%,30%,20%) of N to represent its availability in the model. Corn 15tons/ac--> 37lb/ac N, 26lb/ac P incorporated (8in) on April 24 and 22lb/ac N and 15lb/ac N incorporated (8in) on June 11 and August 11 respectively. Hay (yr1) 5ton/ac manure --> 25lb/ac N and 9lb/ac P incorporated (8in) on Jun 15, Jul 20, and Aug 30. Hay(2yr) same amounts as for yr-1 applied on Jun 5, Jul 10 and Aug 15.
23	Conv. Till --> > Conv. Till + Nutrient Management. 6 months manure storage + plowdown incorporation relative to daily surface spreading	Crowder & Young 1985 CREAMS	Tillage practices, planting and other management practices equal for all 3 years. Duffield series are deep, well drained with high moisture holding capacity. Goon internal drainage due to underlying limestone. Highly productive soil. Losses of NO3 are leached through the root zone and assumed to be delivered via groundwater . Therefore no return of subsurface flow is assumed into the streams. Sediment delivery from erosion in Lancaster county is approximately 20% (Crowder & Young, 1985) Winter cover modeled after harvest of corn silage. Rye was planted in late September producing residue of 2,000 lbs /ac. Corn and Hay residue management adequate so no winter cover was modeled for this case. N and P2O5 at minimum levels of crop requirements. Applications of these nutrients modeled from combined manure, commercial fertilizer and legumes. Commercial Fertilizer plowed under conventional tillage and surface applied for no-till. Crop requirements: Corn grain (120 bush) 120lb/ac N, and 30lb/ac P2O5; Corn Silage(20tons) 140lb/acN and 32lb/ac of P2O5; Alfalfa hay: Establishment year (2.9Tons) 20lbs/ac N and 20lbs/ac of P2O5, meadow:(4.4Tons) 20 lb/ac of P2O5; and Grass pasture (2.5 tons) 50lb/ac N and 50lb/ac of P2O5. Manure applications of daily spreading modeled just before planting and after harvesting. Also disposal in late fall and late winter were modeled. No field was manured more than 4 times a year.
24			
25			
26	Conv Till --> > Conv. Till + Nutrient Management. Injection relative to plowdown incorporation	Crowder & Young 1985 CREAMS	
27			
28			

CONVENTIONAL TILLAGE --> > CONSERVATION TILLAGE WITH NUTRIENT MANAGEMENT

Table A-3-A. Conservation Tillage with Nutrient Management: Reduction Efficiencies[1]

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
1	Conv. Till -> > No Till + Nutrient Management **No Till relative to spring plow conventional tillage**	Whitaker et al. 1978 reported by Casman, 1990	?	?	?	?	?	?	?	?	?	?	?	-17/?	?	?	?	?
2			?	?	?	?	?	?	?	?	?	?	?	89/?	?	?	?	?
3			?	?	?	?	?	?	?	?	?	?	?	-179/?	?	?	?	?
4			?	?	?	?	?	?	?	?	?	?	?	-8/?	?	?	?	?
5			?	?	?	?	?	?	?	?	?	?	?	4/?	?	?	?	?
6	Conv. Till -> > No Till + Subsurface Banding	Adraski 1985 reported by Casman, 1990	?	?	81/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
7	Conv. Till -> > Chisel Till + Subsurface Banding		?	?	70/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
8	Conv. Till -> > Till Plant + Subsurface Banding		?	?	59/?/?	?	?	?	?	?	?	?	?	?	?	?	?	?
9	Conv. Till -> > No Till + Nutrient Management Subsurface Injection **relative to surface** application	Mostaghimi et al. 1988 Rainfall Simulator	?	?	95/?/?	?	?	?	?	40/?	?	?	96/?	?	?	?	?	?
10	Conv. Till -> > No Till + Nutrient Management **no-fertilizer relative to** surface aplication	Mostaghimi et al. 1988	?	?	98/?/?	?	?	?	?	88/?	?	?	99/?	?	?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Waters

Table A-3-A. Conservation Tillage with Nutrient Management: Reduction Efficiencies[1] (cont.)

#	BMP	Investigator	Run-of%	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N %	D-NH4 %	D-NO3 %	D-TKN %
11	Conv. Till -- > > No Till +Nutrient Management. Fertilizer level and Application methods	Shirmohammadi & Shoemaker 1988 CREAMS	11	52/-6/21	63/?/?	46	?	?/-6	?	?	?	92/?	40/?	58/?	40/?	?	?	?
12			25	70/34/44	84/?/?	74	?	?/44	?	?	?	97/?	68/?	72/?	68/?	?	?	?
13			24	73/21/38	77/?/?	69	?	?/21	?	?	?	96/?	64/?	80/?	64/?	?	?	?
14	Conv. Till -- > > No Till +Nutrient Management Fertilizer level Manure storage Application Method	Crowder & Young 1985 CREAMS	?	61/6/37	70/?/?	?	?	?/6	?	?	?	46/?	73/?	23/?	71/?	?	?	?
15			?	61/17/41	67/?/?	?	?	?/17	?	?	?	4/?	73/?	15/?	73/?	?	?	?
16			?	56/25/41	65/?/?	?	?	?/25	?	?	?	-32/?	73/?	-2/?	73/?	?	?	?
17			?	52/-46/10	72/?/?	?	?	?/-46	?	?	?	65/?	73/?	-14/?	73/?	?	?	?
18			?	61/50/69	70/?/?	?	?	?/50	?	?	?	26/?	73/?	18/?	73/?	?	?	?
19			?	61/56/56	66/?/?	?	?	?/56	?	?	?	-14/?	73/?	23/?	73/?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction In Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Water

Table A-3-B. Conservation Tillage with Nutrient Management: BMP Descriptions

#	BMP	Investigator	Location	Size (ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain In[1]
1	Conv. Till --> > No Till + Nutrient Management No Till relative to spring plow conventional tillage	Whitaker et al. 1978 reported by Casman, 1990	Central Missouri	0.02	Nov-Mar/73	Mexico silt loam slowly permeable clay subsoil beginning at a depth of 7 to 18 ins	3	No Till: N banded 4-5 in deep. Plow down = 0lb/ac, at planting = 121lb/ac, side dress = 68lb/ac. Total = 189lb/ac. Spring Plowing conv. tillage: Plow down = 108lb/ac, at planting 13lb/ac, side dress = 68lb/ac. Total = 189lb/ac	corn	38(a)
2					Apr-May/74					
3					June/74					
4					Jul-Oct/74					
5					1973-74					
6	Conv. Till --> > No Till + Subsurface Banding	Adraski 1985 reported by Casman, 1990	Wisconsin	1.35m2	Test on Jun,Jul,Sep 1980-1983	Griswold silt loam	2	At planting fertilizer banded beneath the surface 3-4 in. In 1980,81&82 6-10.6-20 (6-24-24) at rates 214,225, and 241 lb/ac. respectevely. In 1982 670 lb/ac. of 6-3.5-6.6 (6-8-8). Amonium Nitrate in late June or early July at 200 lb/ac. for 1980-82 and 275 lb/ac. in 1983.	corn	2.9 (9/80) 2.9(7/81) 3.5(10/82) 5.3(6/83)
7	Conv. Till --> > Chisel Till + Subsurface Banding									
8	Conv. Till --> > Till Plant + Subsurface Banding									
9	Conv. Till --> > No Till + Nutrient Management Subsurface Injection relative to surface application	Mostaghimi et al. 1988	Virginia	0.025	1988	Groseclose silt loam	8-14	Granular P fertilizer applied at 41lb-P/ac. 24-48 hrs before rainfall simulation.		3.9
10	Conv. Till--> > No Till + Nutrient Management Subsurface Injection relative to no-fertilization									

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-3-B. Conservation Tillage with Nutrient Management: BMP Descriptions (cont.)

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in[1]
11	Conv. Till --> > No Till + Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Upper Potomac sub-basin F	5	1949-78	silty clay loam	8	Dairy and commercial. 7 yr rotation: 1 yr corn grain, 3yr corn silage, and 3 yrs of hay	corn hay	37(a)
12	Fertilizer level Application method		Lower Susquehanna sub-basin A	4.9		silt loam	8	Dairy and commercial. 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
13			Juniata Sub-basin C	6		silt loam	12	Dairy and commercial. 7 yr rotation: 2yr corn grain, 2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
14	Conv. Till --> > No Till + Nutrient Management	Crowder & Young 1985 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	40 Tons/ac of manure. 6 month storage period. Topdress application.	corn grain following corn grain	37-47(a)
15	Fertilizer level Manure storage Application method							20 Tons/ac of manure. 6 month storage period. Topdress application.		
16								10 Tons/ac of manure. 6 month storage period. Topdress application.		
17								40 Tons/ac of manure. 12 month storage period. Liquid manure by injection.	corn grain following alfalfa	
18								20 Tons/ac of manure. 12 month storage period. Liquid manure by injection.		
19								10 Tons/ac of manure. 12 month storage period. Liquid manure by injection.		

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-3-C Conservation Tillage with Nutrient Management: BMP Notes

#	BMP	Investigator	Notes
1	Conv. Till --> > No Till + Nutrient Management	Whitaker et al. 1978 reported by Casman, 1990	Data was read from a histogram. Soluble nitrogen consists of NO3-N and NH4-N. Conventional Tillage is spring plowing with disking before planting. Plots farmed parallel to slope. Corn planted at a final stand of 20,000 to 22,000 plants/ac. in 30 ins rows.
2	No Till relative to spring plow conventional tillage		
3			
4			
5			
6	Conv. Till --> > No Till + Subsurface Banding	Adraski 1985 reported by Casman, 1990	Rainfall was applied for 1 hr. Test areas covered during natural rainfall periods.
7	Conv. Till --> > Chisel Till + Subsurface Banding		
8	Conv. Till --> > Till Plant + Subsurface Banding		
9	Conv. Till --> > No Till + Nutrient Management Subsurface Injection relative to surface application	Mostaghimi et al. 1988	Rainfall sequence same as in Table A-1-C #s 4-8 Twelve experimental plots divided into no-till and conventional tillage. No-Till plots planted in winter rye in the fall of 1985, and cover killed 1 week before rainfall simulation. Conventional plots tilled 4-6 ins deep with rototiller following disking.
10	Conv. Till--> > No Till + Nutrient Management Subsurface Injection relative to no-fertilization		

Table A-3-C. Conservation Tillage with Nutrient Management: BMP Notes (cont.)

#	BMP	Investigator	Notes
11	Conv. Till --> > No Till + Nutrient Management Fertilizer level Application method	Shirmohammadi & Shoemaker 1988 CREAMS	Same as Table A-2-C # 19
12			Same as Table A-2-C # 20
13			Same as Table A-2-C # 22
14	Conv. Till --> > No Till + Nutrient Management Fertilizer level Manure Storage Application method	Crowder & Young 1985 CREAMS	Same as Table A-2-C #s 23-25
15			
16			
17			
18			
19			

CONVENTIONAL TILLAGE --> > CONVENTIONAL TILLAGE WITH NUTRIENT MANAGEMENT AND FARM PLAN

Table A-4-A. Conventional Tillage with Nutrient Management and Farm Plan: Reduction Efficiencies[1]

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
1	Conv. Till -> > Conv. Till + Terraces Grassed Waterways Winter Cover	Langdale et al. 1985 reported by Casman 1990	39	?	66/?/?	75	?	?	?	?	2/?	-10/?	71/?	?	?	?	?	?
2	Conv. Till -> > Conv. Till + Terraces Nutrient Management Appl. Method, Fert. Level	Shirmohammadi & Shoemaker 1988 CREAMS	46	70/34/43	83/?/?	72	?	?/34	?	?	?	98/?	65/?	74/?	65/?	?	?	?
3			37	75/23/40	80/?/?	72	?	?/23	?	?	?	80/?	68/?	81/?	68/?	?	?	?
4	Conv. Till -> > Conv. Till Terraces + Nutrient Management Application Method Manure Storage Fertilizer Level	Crowder & Young 1985 CREAMS	?	56/-24/22	66/?/?	?	?	?/-24	?	?	?	92/?	62/?	37/?	62/?	?	?	?
5			?	56/13/38	64/?/?	?	?	?/13	?	?	?	85/?	62/?	39/?	62/?	?	?	?
6			?	57/20/39	63/?/?	?	?	?/20	?	?	?	74/?	62/?	37/?	62/?	?	?	?
7	Conv. Till -> > Conv. Till + Contour Nutrient Management Application Method Fertilizer Level	Shirmohammadi & Shoemaker 1988 CREAMS	12	46/-5/18	58/?/?	32	?	?/-5	?	?	?	93/?	30/?	93/?	30/?	?	?	?
8			26	50/35/39	66/?/?	30	?	?/35	?	?	?	97/?	29/?	72/?	29/?	?	?	?
9			25	43/52/47	40/?/?	29	?	?/52	?	?	?	92/?	30/?	76/?	30/?	?	?	?
10			26	58/24/35	58/?/?	69	?	?/24	?	?	?	97/?	31/?	80/?	31/?	?	?	?
11	Conv. Till -> >Conv. Till + Stripcropping, Diversions, Grassed Waterways, Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	25	82/48/67	89/?/?	90	?	?/48	?	?	?	92/?	89/?	65/?	89/?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Water

Table A-4-B. Conventional Tillage with Nutrient Management and Farm Plan: BMP Descriptions

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain In[1]
1	Conv. Till -> > Conv. Till + Terraces,Grassed Waterways Nutrient Management WinterCover	Langdale et al. 1985	Upland watersheds in the Southern Piedmont	3.2-6.7	1974-1976	Cecil sandy loam		P fertilizer incorporated in spring and surface applied during the fall. Single crop 18lb/ac P	corn rye cover	40(a)
2	Conv. Till -> > Conv. Till + Terraces Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Lower Susquehanna snub-basin A	4.9	1949-78	silt loam	8	Dairy and commercial. 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
3			Juniata Subbasin C	6		silt loam	12	Dairy and commercial. 7 yr rotation: 2yr corn grain, 2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
4	Conv. Till --> > Conv. Till + Terraces Nutrient Management	Crowder & Young 1985 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	40 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).	corn grain following corn grain	37-47(a)
5								20 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
6								10 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
7	Conv. Till --> > Conv. Till + Contour Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Upper Potomac sub-basin F	5	1949-78	silty clay loam	8	Dairy and commercial. 7 yr rotation: 1 yr corn grain, 3yr corn silage, and 3 yrs of hay	corn hay	37(a)
8			Lower Susquehanna sub-basin A	4.9		silt loam	8	Dairy and commercial. 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
9			North Branch Susq. sub-basin E	5.4		sandy clay loam	10.5	Dairy and commercial. 7 yr rotation: 3 yr corn silage, and 4 yrs of hay.	corn hay	34(a)
10			Juniata Subbasin C	6		silt loam	12	Dairy and commercial. 7 yr rotation: 2yr corn grain, 2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
11	Conv. Till -> > Conv. Till + Stripcropping, Diversions, Grassed Waterways, Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	North Branch Susq. sub-basin E	5.4	1949-78	sandy clay loam	10.5	Dairy and commercial. 7 yr rotation: 3 yr corn silage, and 4 yrs of hay.	corn hay	34(a)

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-4-C. Conventional Tillage with Nutrient Management and Farm Plan: BMP Notes

#	BMP	Investigator	Notes
1	Conv. Till -> > Conv. Till + Terraces + Nutrient Management Winter Cover	Langdale et al. 1985 reported by Casman 1990	Paired watershed study representing land forms of the Piedmont. Cropping Sequence: Non-terraced watershed--> May-Oct 1974 Corn, Nov 1974-Apr 1975 Fallow, May-Oct 1975 Corn, Nov 1975-May -1975 not determined. Terraced watersheds---> May-Oct 1974 Corn, Nov 1974-Apr 1975 Rye(cover), May-Oct 1975 Corn, Nov 1975-May 1976 Barley. Fertilizer level based on soil tests.
2	Conv. Till -> > Conv. Till + Terraces + Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Same as in Table 4-C # 20
3			Same as in Table A-2-C # 22
4	Conv. Till --> > Conv. Till + Terraces Nutrient Management	Crowder & Young 1985 CREAMS	Same as In Table A-1-C #s 53-58
5			
6			
7	Conv. Till --> > Conv. Till + Contour Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Same as In Table A-2-C # 19
8			Same as in Table A-2-C # 20
9			Same as In Table A-2-C # 21
10			Same as In Table A-2-C # 22
11	Conv. Till -> > Conv. Till + Stripcropping, Diversions, Grassed Waterways, Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Same as in Table A-2-C # 21

CONVENTIONAL TILLAGE --> > CONSERVATION TILLAGE WITH NUTRIENT MANAGEMENT AND FARM PLAN

Table A-5-A. Conservation Tillage with Nutrient Management and Farm Plan: Reduction Efficiencies[1]

#	BMP	Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	NO3 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
1	Conv. Till -> > No Till + Contour and Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	17	59/-9/22	72/?/?	60	?	?/-9	?	?	?	93/?	54/?	61/?	54/?	?	?	?
2			30	73/33/44	86/?/?	78	?	?/33	?	?	?	97/?	73/?	72/?	73/?	?	?	?
3			25	82/48/67	89/?/?	90	?	?/48	?	?	?	92/?	89/?	65/?	89/?	?	?	?
4			37	75/20/38	79/?/?	?	?	?/23	?	?	?	97/?	68/?	81/?	68/?	?	?	?
5	Conv Till -> > Min. Till + Terraces, Contouring, Stripcropping Sod Waterways Nutrient Management	Crowder & Young 1985 CREAMS	?	75/-28/30	86/?/?	?	?	?/-28	?	?	?	92/?	86/?	41/?	86/?	?	?	?
6			?	77/9/47	85/?/?	?	?	?/9	?	?	?	84/?	86/?	43/?	86/?	?	?	?
7			?	76/17/48	84/?/?	?	?	?/17	?	?	?	69/?	86/?	41/?	86/?	?	?	?
8			?	68/-41/11	86/?/?	?	?	?/-41	?	?	?	90/?	85/?	19/?	85/?	?	?	?
9			?	69/6/34	84/?/?	?	?	?/6	?	?	?	57/?	85/?	6/?	85/?	?	?	?
10			?	69/4/38	83/?/?	?	?	?/4	?	?	?	34/?	85/?	11/?	85/?	?	?	?
11	Conv. Till -> > Min. Till + Terraces and Grassed Waterways	DelVecchio & Knisel 1982 CREAMS	?	99/-12/45	99/?/?	?	?	?/-12	?	?	?	77/?	99/?	82/?	99/?	?	?	?
12	Conv. Till -> > No Till + Filter Strip	Ross et al. 1990 Rainfall Simulator	90	91/?/?	97/?/?	99	86/?	97/?	91/?	80/?	?	80/?	?	?	?	?	?	91/?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Reduction Efficiencies given for Surface Water

Table A-5-B. Conservation Tillage with Nutrient Management and Farm Plan: BMP Descriptions

#	BMP	Investigator	Location	Size(ac.)	Years	Soil	Slope %	Fertilization Level/ Farm Activity	Crop	Rain in[1]
1	Conv. Till --> > No Till + Contour and Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Upper Potomac sub-basin F	5	1949-78	silty clay loam	8	Dairy and commercial. 7 yr rotation: 1 yr corn grain, 3yr corn silage, and 3 yrs of hay	corn hay	37(a)
2			Lower Susquehanna sub-basin A	4.9		silt loam	8	Dairy and commercial. 7 yr rotation: 2 yr corn grain, 2yr corn silage, 1yr soybeans and 2yrs of alfalfa hay.	corn soybeans hay	42(a)
3			North Branch Susq. sub-basin E	5.4		sandy clay loam	10.5	Dairy and commercial. 7 yr rotation: 3 yr corn silage, and 4 yrs of hay.	corn hay	34(a)
4			Juniata Sub-basin C	6		silt loam	12	Dairy and commercial. 7 yr rotation: 2yr corn grain, 2 yr corn silage and 4 yrs of hay.	corn hay	38(a)
5	Conv. Till --> > Min. Till + Terraces, Contouring, Stripcropping Sod Waterways Nutrient Management	Crowder & Young 1985 CREAMS	Lancaster Co. PA		3	Duffield silt loam	5	40 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).	corn grain following corn grain	37-47(a)
6								20 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
7								10 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
8								40 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).	corn grain following alfalfa	
9								20 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
10								10 Tons/ac of manure. 12 month storage period. Incorporation using a plow (plowdown).		
11	Conv. Till--> > Min. Till CREAMS	DelVecchio & Knisel 1982	Southern		1955-74	Tifton Loamy Sand			3yr rotation	-
12	Conv. Till --> > No Till + Filter Strip	Ross et al. 1990	Prince Edward Co. VA	0.14	7/26-27/89	Appling fine sandy loam	4	5/89: planted millet & 50lb-N/ac 7/89: planted corn	Corn	3.2

1. Rainfall given for individual storms events unless specified as annual average (a)

Table A-5-C. Conservation Tillage with Nutrient Management and Farm Plan: BMP Notes

#	BMP	Investigator	Notes
1	Conv. Till --> > No Till + Contour and Nutrient Management	Shirmohammadi & Shoemaker 1988 CREAMS	Same as Table A-2-C # 19
2			Same as Table A-2-C # 20
3			Same as Table A-2-C # 21
4			Same as Table A-2-C # 22
5	Conv. Till --> > Min. Till + Terraces, Contouring, Stripcropping Sod Waterways Nutrient Management	Crowder & Young 1985 CREAMS	Same as Table A-2-C #s 23-25
6			
7			
8			
9			
10			
11	Conv. Till--> > Min. Till CREAMS	DelVecchio & Knisel 1982	Same as Table A-1-C # 52
12	Conv. Till --> > No Till + Filter Strip	Ross et al. 1990 Rainfall Simulator	Same as Table A-1-C

ANIMAL WASTE MANAGEMENT

Table A-6. Animal Waste Management: Nutrient Reduction Efficiencies[1]

#	BMP	Investigator	Practice	TN %	TP %	Notes
1	Animal Waste Management	Casman 1990	180-day manure storage	5	8	Assume manure lost at four points: collection, storage, application and weathering i.e. a) With Storage, TN-- > > collection: 20% , storage: 5% , application 15%; Total = 40% TP-- > > collection: 20% , storage: 0% , application 15%; Total = 35% b) Without Storage TN-- > > collection: 20% , winter loss: 7% , stack loss: 4% , application: 15% ; Total = 46% TP-- > > collection: 20% , winter loss: 7% , stack loss: 4% , application: 15% ; Total = 46% Without storage manure is collected, stacked in heaps and spread weekly. When crop is in the field manure is spread in an idle field. In the winter (for two moths) 50% of the manure applied is lost. A 180-day storage structure gives less nutrient reduction compared to weekly spreading because the manure storage during the growing season must be applied in the fall. In conclusion, manure storage is effective in reducing nutrients when the storage manure can be substituted for fertilizer, Casman (1990).
2			1-year manure storage	17	23	
3			clean water protection[2]	< 20	< 20	
4			1-year storage and 15% fertilizer application reduction	20	20	
5			1-year storage, clean water protection and 15% fertilizer application reduction	40	40	

1. Conceptual estimates of annual reduction efficiencies for ground and surface waters combined
   Efficiencies given have not yet been confirmed in the field.

2. BMPs for preventing clean water (rainfall) contamination with manure (i.e. runoff guttering, diversions, etc.)

VEGETATED FILTER STRIPS AND GRASSED WATERWAYS

Table A-7-A. Vegetated Filter Strips and Grassed Waterways: Reduction Efficiencies[1]

#	Filter Strip		Investigator	Run-off %	TN %	TP %	Soil %	NH4 %	N03 %	TKN %	PO4 %	D-PO4 %	D-P %	Par P %	D-N %	Par N	D-NH4 %	D-NO3 %	D-TKN %
	Slope(%)	length(ft)																	
1	11	30	Dillaha et al. 1988 reported by Casman 1990	25	77/?/?	80/?/?	95	69/?	4/?	80/?	30	?	35/?	?	?	?	?	?	67/?
2		15		-6	61/?/?	63/?/?	87	34/?	-36/?	64/?	-20/?	?	33/?	?	?	?	?	?	51/?
3	16	30		1	71/?/?	57/?/?	88	-35	17/?	72/?	-51/?	?	37/?	?	?	?	?	?	76
4		15		16	67/?/?	52/?/?	76	-21/?	3/?	69/?	-108/?	?	-49/?	?	?	?	?	?	60
5	5x4	30		-1	7/?/?	19/?/?	58	-11/?	-158/?	9/?	31/?	?	?	?	?	?	?	?	?
6		15		8	0/?/?	2/?/?	31	1/?	-82/?	1/?	-3/?	?	?	?	?	?	?	?	?
9	3	30	Magette et al. 1987 reported by Casman 1990	?	41/87/83	42/?/?	82	?	?	?	?	?	?	?	?	?	?	?	?
10		15		?	-15/-10/-20	22/?/?	65	?	?	?	?	?	?	?	?	?	?	?	?
11	4	30		?	48/?/?	25/?/?	82	?	?	?	?	?	?	?	?	?	?	?	?
12		15		?	-6/?/?	27/?/?	66	?	?	?	?	?	?	?	?	?	?	?	?
13	5	30		?	51/3/11	52/?/?	86	?	?	?	?	?	?	?	?	?	?	?	?
14		15		?	-17/39/36	41/?/?	72	?	?	?	?	?	?	?	?	?	?	?	?
15	2	85	Schwer & Clausen[2] 1985	?	?	90	95	78	?	92	92	?	?	?	?	?	?	?	?
16	Grassed Waterways		Casman 1990	?	0-2	0-15	?	?	?	?	?	?	?	?	?	?	?	?	?

1. X/Y/Z = > Nutrient Reduction in Surface Water (X), Groundwater (Y), Total (Z).
X/Y = > Nutrient Reduction in Surface Water (X), Groundwater (Y)
Z = > Total Nutrient Reduction (Surface Water and Groundwater)
? = > Not Measured or Information not Available
Runoff and Soil Loss Reduction Efficiencies given for Surface Waters

2. Vegetated filter strips for treatment of milking parlor waste water.

Table A-7-B. Vegetated Filter Strips and Grassed Waterways: BMP Notes

#	Filter Strip		Investigator	Notes
	Slope(%)	length(ft)		
1	11	30	Dillaha et al. 1988 reported by Casman 1990	Use of vegetated filter strips to treat feedlot runoff. Rainfall was applied to a feedlot-like uphill from the strip area with a rainfall intensity similar to the 2yr storm.
2		15		
3	16	30		
4		15		
5	5x4	30		
6		15		
9	3	30	Magette et al. 1987 reported by Casman 1990	Two weeks duration of the test using rainfall simulator. Plots were on sandy loam soils in the coastal plain of Maryland. Tests were done in a two month period during the growing season.
10		15		
11	4	30		
12		15		
13	5	30		
14		15		
15	2	85	Schwer & Clausen 1985	Vegetated filter strip for treatment of milking parlor water. The soil was loam with a 2% slope. A mixture of fescue, rye and bluegrass was seeded.
16	Grassed Waterways		Casman 1990	