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ABSTRACT

Increased nutrient and sediment losses from expanding agricultural practices and urban development in Arkansas are important environmental concerns. Best Management Practices (BMPs) are being implemented to lessen the effects of these developments on existing water bodies. There is, however, insufficient scientific base as to the effectiveness of these practices. A number of studies have been conducted in recent years to determine BMP effectiveness. Data from these studies can only be reliably used for the individual site from which they were obtained. When considered collectively, these data comprise quantitative effectiveness over a wide range of conditions and can thus be used to provide reliable estimates of BMP effectiveness. This study develops a tool for estimating BMP effectiveness, based on accumulation and analyses of data reported in previous studies, with a focus on site conditions and management interventions in Arkansas. This study incorporates data from a variety of regions in the southeastern U.S., which have site conditions and management similar to those in Arkansas. Developed within Microsoft® Access© from a pre-existing BMP characterization tool, this tool will be made accessible to local and state agencies and will aid rural and urban planners in developing management solutions for nutrients and sediment control. The tool describes individual BMPs in detail and gives site-specific estimates of their long-term effectiveness in sediment and nutrient control.

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INTRODUCTION

Agriculture is the number one source of impairment to surfacewater (USEPA, 2000). As of 2002, over 14.5 million acres (43.5%) of Arkansas land were in agricultural production (FedStats, 2006; USDA National Agricultural Statistics Service, 2006). Agriculture is listed as the source of impairment for 764.4 miles (9.7%) of Arkansas streams (Arkansas Department of Environmental Quality, 2002), with sediment and nutrients being the major pollutants of concern.

Healthy aquatic environments require the nutrients nitrogen (N) and phosphorous (P); however, those nutrients in excess can deteriorate the health of aquatic bodies by encouraging rapid algal growth (USEPA, 2001). Algal bloom from excessive nutrients starts the process of eutrophication, where excessive growth removes dissolved oxygen from the water, asphyxiating aquatic organisms including fish. Eutrophication can cause serious health problems and restricts industrial use (Martin and Cooke, 1994; Sharpley et al., 2003; Sharpley et al., 2000). Eutrophic waters make swimming, fishing, and navigation difficult and are cloudy or green (Khan and Ansari, 2005).

Most sediment pollution occurs when topsoil is carried away with runoff during a storm event (USEPA, 2005). Sediments can carry nutrients, metals, pesticides, and toxic organics (Novotny and Olem, 1994). Sediments degrade water quality, inhibit aquatic life, fill in culverts, lakes, and streambeds, and increase the difficulty of navigation (Cooper and Lipe, 1992).

Best management practices (BMPs) are intended to reduce the negative environmental consequences of land use and maintain the productivity of the land (Heatwole et al., 1991). The USDA has over 160 BMPs approved for use on agricultural areas and about 90 urban BMPs (USDA-NRCS, 2006a; USDA-NRCS, 2006b). The Natural Resources Conservation Service (NRCS) often advises farmers on BMP selection to attain water-quality improvements. There is, however, some question as to how effective these BMPs are in preventing pollutant movement into surfacewaters, with effectiveness being defined as the percentage by which nutrients or sediment are reduced by the BMP. BMPs are costly and some may require significant alteration in routine management operations, thus the need to determine the potential effectiveness of the BMPs before BMPs are implemented. BMP effectiveness can be influenced by several factors, including site conditions, agricultural activity, and extent of implementation. Various studies have been performed to determine effectiveness based on these factors; however, there is no conclusive definition of the effectiveness of any one BMP. Individual

MEET THE STUDENT-AUTHOR

Katherine R. Merriman

I graduated from Jonesboro High School in 2001. I was awarded a Humphries' Chancellor's Scholarship after my first semester studying chemical engineering at the University. In spring 2003, I took an internship with a major oil company. Although it was a great learning experience, I decided that oil would most likely take me away from Arkansas and I was determined to stay in state. I then changed my major to Biological & Agricultural Engineering with a focus on ecological engineering. In the summer of 2004, I worked for the USDA-National Resources Conservation service in my hometown of Jonesboro. During the following academic year, I worked part-time for Dr. Indrajeet Chaubey on several water quality-related projects. I am a member of Gamma Sigma Delta, (the honor society of agriculture), and Tau Beta Pi, (an engineering honor society). After receiving my B.S. in biological engineering, I plan to enroll in graduate school at the University of Arkansas under Dr. Chaubey and study natural resources management using remote sensing technology.

studies may only be applicable for the site where the BMP was applied. A compilation of these individual studies gives a wide range of data of BMP effectiveness for the varying influencing factors.

BMP effectiveness, as reported in the literature, varies widely. For example, two different studies reported on the effectiveness of an alternative watering facility for cattle, but gave dissimilar sediment reduction values. Line et al. (2000) reported a 38% reduction in sediment while Sheffield et al. (1997) reported 89% sediment reduction effectiveness.

The objective of this study was to quantify BMP reduction effectiveness under various site characteristics, land use, and study methods based on the literature and to provide a tool with which site-specific effectiveness estimates can be made. The Gitau et al. (2005) BMP tool provided a foundation for development of a new tool, where the data are focused on BMPs implemented in Arkansas.

MATERIALS AND METHODS

This study expounds upon the BMP database and tool developed by Gitau et al. (2005). The original database focused on P pollution problems and management interventions in New York City watersheds. Data collected included particulate, dissolved, and total P (PP, DP, and TP). Many features were left intact, but some changes were necessary to expand its reach to include data for nitrate (NO_3-N), ammonium (NH_4-N), total N (TN), and total sediment reduction effectiveness. The Gitau et al. (2005) BMP database tool was re-designed to fit the expanded data set while making the data more accessible.

Tool structure

The Gitau et al. (2005) BMP tool is designed to run from four main tables. Its primary table, "Effectiveness Table," holds all of the data relating to the effectiveness of the BMP reference, including the effectiveness reduction and the site and study characteristics. The secondary tables, "BMP Attributes Table" and "References Table", support the "Effectiveness Table." These two tables maintain relevant information about the BMPs and citations useful for further queries about the individual records in the database. The final table is the main look-up table, "Choices Table." This table provides information that is read into several drop-down lists. Some of its fields are: BMP class, hydrologic soil-group (HSG), slope, a list of commonly cited journals, and other commonly used records. Fig. 1 provides a schematic to the original tool. Since the original BMP database was developed specifically for P reductions, expansion was necessary to integrate N and sediment data. Additional alterations were required to enable improved data flow and ensure data integrity. Fig. 2 illustrates the flow of data stored within the database. The major difference between the structures of the two databases is in the look-up tables.

The Effectiveness Table received additional fields for quantitative and qualitative values of NO_3-N, NH_4-N, TN, and total sediment. The location field was changed to reflect the state of study, instead of the region of study, since now only sites in the Southeast or states adjacent to Arkansas were considered. A "Detailed Location" field was included for a more specific location of the study such as the Arkansas Delta, Tennessee River Valley, or Georgia Coastal Plain.

The structure of the BMP Attributes Table was untouched. However, the number of BMPs listed increased from 32 to 201. This increase reflects the addition of the entire list of National Conservation Practice Standards used by the NRCS (USDA-NRCS 2006a). At the time of the addition, the NRCS listed 163 National Conservation Practice Standards. Some of the standards contain multiple methods of compliance. Each method was allotted a separate entry to ease searching among the BMP references. For example, several literature resources contain data on the reduced-till conservation tillage method though it is not listed in the National Conservation Practice Standards. It is a part of NRCS Practice code 329, Residue Management/No-Till/Strip Till/Direct Seed. Reduced till is thereby listed as a separate BMP from no-till, strip till, and direct seed, but all of these have NRCS code 329.

Also, physical variables within some BMPs directly influence their effectiveness. For instance, the effectiveness of a vegetative filter strip (NRCS conservation practice code 393) depends on the filter strip's length; the 2-m filter strip and the 15-m filter strip have distinctly different effectiveness. These BMPs require supplementary details visible when documenting effectiveness. BMPs of this type are listed in the BMP Attributes Table multiple times for each different physical variable of the same BMP; therefore a 2-m filter strip would be found as "Vegetative Filter Strip (2-m)" and a 15-m strip as "Vegetative Filter Strip (15-m)." Additionally, the National Conservation Practice Standards' definitions were input to aid in BMP selection from the BMP Attributes Table to allow future users to makes such distinctions.

The References Table received minor modifications. Two fields were inserted: "Issue number" and "Chapter number." An Electronic Address field was also added to accommodate the web address of any internet material found.

The Choices Table was disassembled and restructured into several, smaller tables. Several small look-up tables increase the query-processing speed and reduce data loss by removing the complicated relationships between the Choices Table and the three other main tables. These tables are smaller and are related directly to the fields in either the primary or secondary tables. This change ensures referential integrity.

Data collection

The scope of this work considers studies completed in the southeastern U.S. (the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) and studies completed in states adjacent to Arkansas (Missouri, Oklahoma, and Texas). Some of the original references in Gitau et al. (2005) were completed outside the study area and these were removed.

Since Gitau et al. (2005) focused on P reduction, the references were re-evaluated for N and sediment reduction data. A literature review searched for reduction effectiveness of various BMPs applied in Arkansas and the other states. The BMP and agricultural activity for each study were documented for each record of BMP effectiveness. Site conditions and study characteristics, such as HSG, slope, study method, scale, and location, were recorded. Notes on the study method and comments on the study were taken. For each reference, these data were compiled in the database. Details of the full citation were also collected. An abbreviated citation, called "Short Name," was given to each reference.

Fig. 3 shows what data were collected and stored. The citation data are stored in the References Table, while all site and study characteristics and effectiveness data are stored in the Effectiveness Table. These data sets are linked by the Short Name field.

Tool development

Utilizing the BMP database, a BMP effectiveness tool was developed to allow user evaluation of BMPs based on their specified soils and slopes. Data were organized into 14 BMP classes (i.e. alternative water supply, animal-waste systems, barnyard-runoff management, conservation tillage, contour-strip crop, crop rotation, drainage systems, filter strips, nutrient management plan, riparian forest buffers, rotational grazing, stream fencing, terraces, and wetland), and then further segregated into three categories: Barn Yard Management, Erosion Control, and Nutrient Management. The BMP effectiveness data were arranged so that they could be queried by soil group, slope, or combinations of the two. This allows users to determine a mean, range, and standard deviation for individual BMP effectiveness based on specified soil and slope conditions.

The tool was also designed to allow users to search the BMP data in several different manners other than by soil group or slope. Through the tool, the data can be compiled based upon agricultural activity, reduction effectiveness, BMP class, site conditions (soil or slope), or reference citation. The user can further customize the BMP tool with any entries from the BMP database.

An urban BMP effectiveness estimator tool is currently being developed.

RESULTS AND DISCUSSION

BMP tool

According to Gitau et al. (2005), site location, slopes, and soils are the key factors affecting BMP effectiveness. For this tool, data were grouped by HSG, slope, and BMP. Location was considered by restricting data entry to studies in the southeastern states and Missouri, Oklahoma, and Texas. Like the Gitau et al. (2005) BMP tool, the tool's various features are accessed through interfaces.

The main interface is the principal interface; it is automatically opened when the BMP database is launched in Microsoft® Access©. The main interface contains links to general descriptive data on BMPs and BMP classes. Several other interfaces are available from the main interface. The BMP effectiveness estimates interface provides access to the BMP effectiveness estimator, which is the foundation of the BMP tool. This user-driven estimator is written in the query language of Microsoft® Access©, Structured Query Language (SQL). Queries run through SQL are executed at run time, hence outputs are current and reflective of any updates to the database. The estimates are sorted by BMP, a change from the Gitau et al. (2005) database, where the estimates were quantified by BMP class. The estimates are made by averaging the literature data for combinations of HSG and slope if BMP data are available for them. Where the database has no information for a particular combination of BMP class, slope, and soil group, the estimator returns blank fields and refers the user to the Averaged Data interface described in the ensuing paragraph. The procedure to obtain effectiveness results is shown in Fig. 4.

The Averaged Data interface, another addition to the BMP tool, is directly accessed through the main interface. This interface provides average BMP effectiveness values regardless of site, soils, and slopes. This interface references the NRCS code for the BMP and its NRCS descriptive definition. The averages are arranged by BMP class and only the BMPs with quantitative effectiveness data are listed.

The View Summaries interface opens a summary for each nutrient and sediment. These reports show the reduction effectiveness categorized by BMP class. For each BMP class, statistical properties, such as average, minimum, maximum, standard deviation, and count of records of the data, are returned. Only the BMP classes that contain quantitative effectiveness data are shown.

The Effectiveness Details interface lists all the individual data under the short name of its citation. This interface provides an easy way to search the specific effectiveness records without toiling through the complete Effectiveness Table. The BMP, site, and study characteristics are given. Access to the full citation is also provided. Similarly, the Search by Authors interface lists the citations for all the data. It provides a user-friendly forum to directly search the citations referenced in the tool rather than the References tables. The Access filters can also sort and search the fields in both interfaces.

The Updater interface updates the different database tables. All data, citation or effectiveness, can be edited from the Updater interface. Several of the different fields (BMPs, BMP class, journals, and agricultural activities) used in the look-up tables are updated here.

Data summary

Table 1 lists some of the effectiveness estimator results. The negative values indicate a decrease in BMP effectiveness; blank values mean there are no data for the given site conditions. Total sediment reduction had the most entries for any BMP and also the greatest ranging percentage reduction (from 19 to 97%). There were only four estimates for particulate P (PP%). For the data shown, most data collected thus far were for vegetative filter strips or no-till with 17 and 23 results for all slope and soil group combinations, respectively. No-till with 3-8% slopes and type C soil had the greatest number of references; its effectiveness estimates for total sediment, TP, and TN were 78, 84, and 90%, respectively.

Example application

A farm, with hydrologic soil-group C soils and a slope between 3-8%, in eastern Arkansas has been designated as having contributed to sediment pollution. This farm cultivates row crops. The farm's planners feel they need to install BMPs in order to control their sediment problem. However, choice of the BMP is not clear.

Using the tool, the farm planners select site conditions similar to their own. They choose the BMP category they are interested in (in this case, erosion control). They are able to determine which BMPs are the most effective in preventing sediment pollution. Under these conditions, estimates of BMP effectiveness are obtained for four BMPs (Fig. 4).The most effective BMP to reduce sediment pollution is reduced tillage, which has a 92% effectiveness estimate for sediment reduction. The blank fields in Fig. 4 indicate no nutrient data are available for reduced tillage. No-till or pasture and hay planting have estimates of 57 and 59%, respectively. Fig. 5 shows the results graphically. Estimates for different soil and slope combinations can be obtained similarly, thus facilitating BMP selection.

This tool is an aide to effectiveness-based BMP selection. It allows effectiveness estimates to be determined for combinations of hydrologic soil-group and slope, averaged general BMP effectiveness estimates, or nutrient and sediment summary reductions. This tool will be made accessible to local and state agencies and will aid rural and urban planners in developing management solutions for nutrient and sediment control. The tool was designed for Arkansas conditions; but because its base data were derived from a variety of site conditions within the southeastern U.S., it would be appropriate for use within the surrounding region where site conditions and management interventions are similar to those in Arkansas. With a few modifications and additional data entry, the tool could be applicable elsewhere in the U.S.

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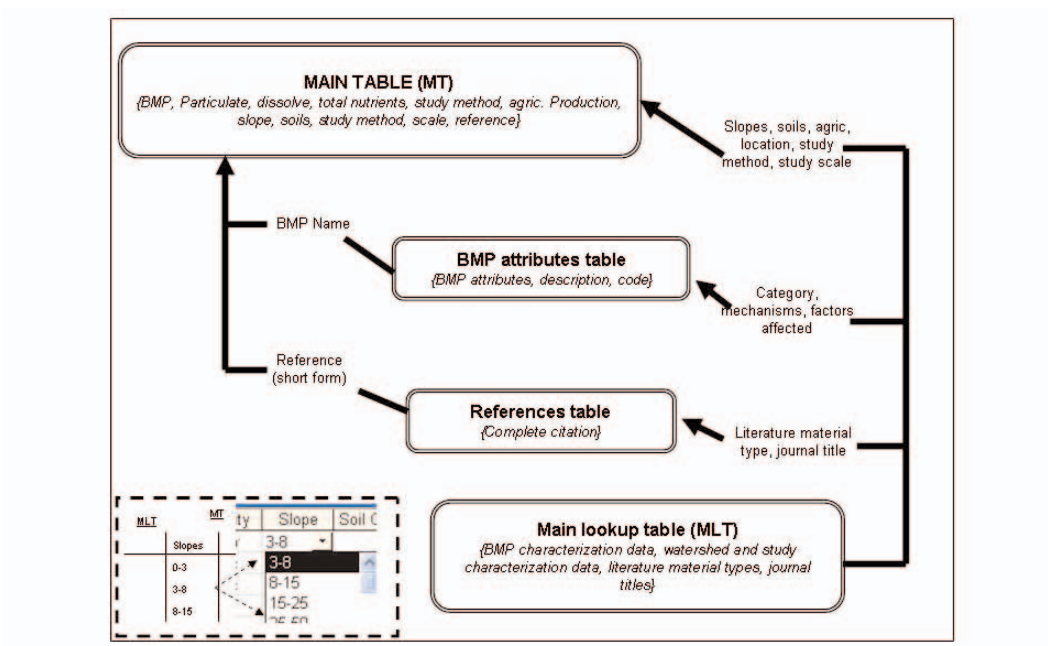

Fig. 1. Database schematic showing component tables, contents, and table linking (Adapted from Gitau, et al. 2005).

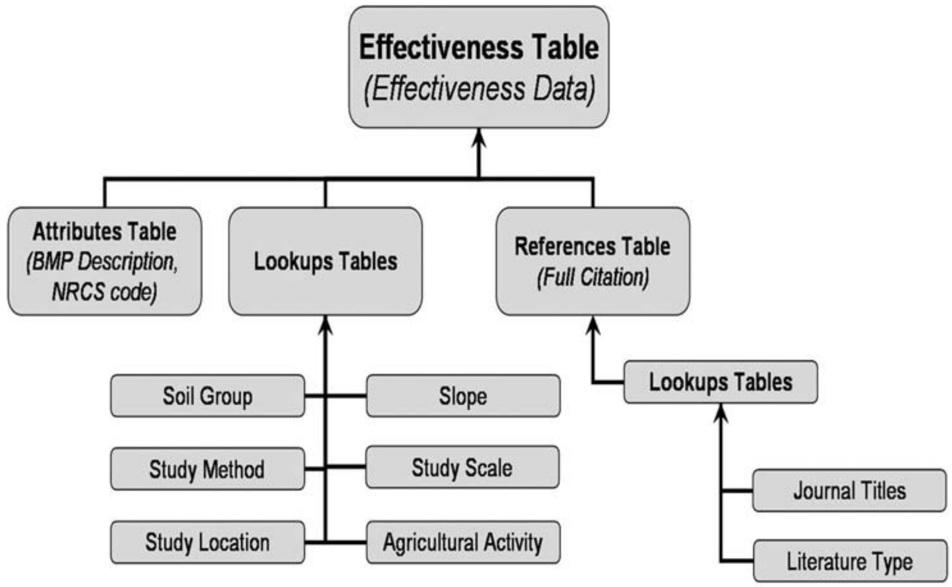

Fig. 2. Database schematic.

References table:

Authors	Journal title	Volume number	Book title	Has BMP data?
Year	Article title	Issue number	Publisher	Combined BMP data
		Chapter number	Address	Ag or Urban BMP
Short name		Pages numbers	Web address	

Effectiveness table:

Bmp name	Agricultural activity	Study method	**Reduction effectiveness in:**
Bmp class	State	Study scale	Dissolved P
	Detailed location	Method description	Particulate P
	Slope	Comments	Total P
Short name	Soil group		Ammonium N
			Nitrate N
			Total N
			Total Sediment

Fig. 3. Data taken from the literature, showing how the References and Effectiveness Tables are connected. P = Phosphorus; N = Nitrogen

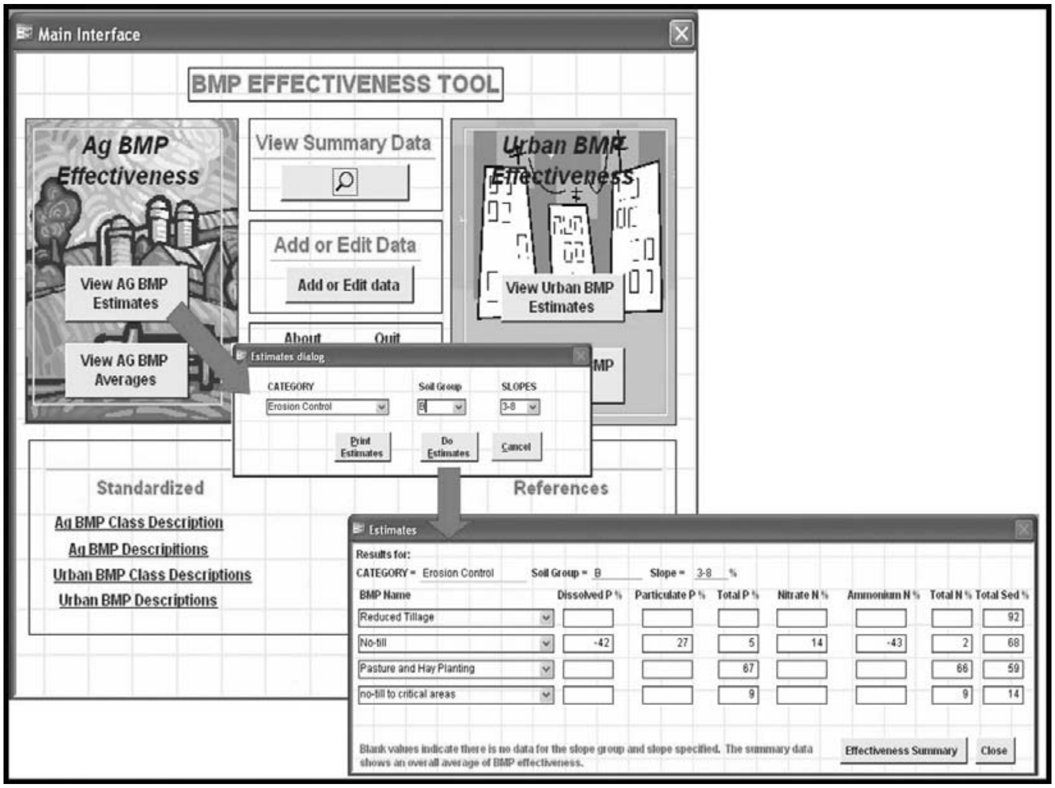

Fig. 4. Schematic of the Effectiveness Estimator.

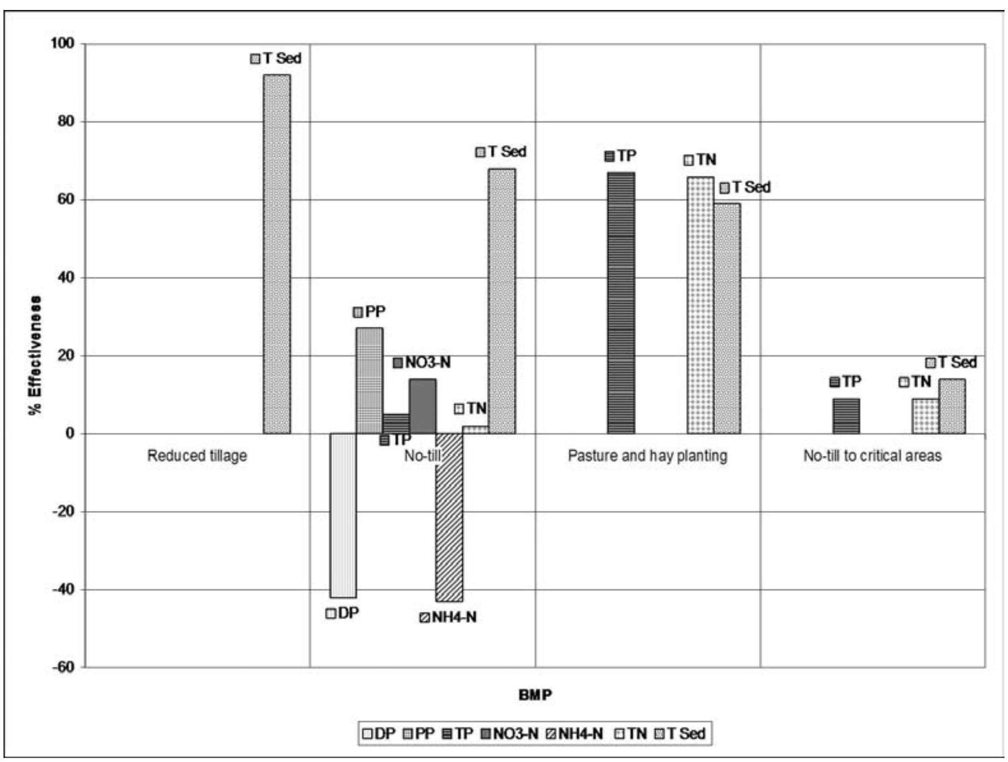

Fig. 5. Graphical results of the Effectiveness Estimator. DP = Dissolved Phosphorus, PP = Particulate Phosphorus, TP = Total Phosphorus, NO_3-N = Nitrate Nitrogen, NH_4-N = Ammonium Nitrogen, TN = Total Nitrogen, and T Sed = Total Sediment.

Table 1. Selected BMP effectiveness estimates based on slope and soil group.

BMP name	Slope %	HSG[a]	T Sed %[b]	PP %	DP %	TP %	NO_3-N %	NH_4-N %	TN %	Count[c]
Contour buffer strips (3- m)	3-8	B				30	10		17	2
Contour buffer strip (4.5-m)	0-3	D	19			26	39	32	20	1
	3-8	D	19			26	39	32	20	1
No-till	0-3	B	86							1
	0-3	C	68							2
	3-8	B	68	27	-42[d]	5	14	-43	2	5
	3-8	C	78			84			90	11
	3-8	D	16							1
	8-15	C	87	71	71	78	37	57	91	3
Pasture and hay planting	3-8	B	59			67			66	1
Reduced tillage	3-8	B	92							1
	3-8	C	75							2
	3-8	D	14							1
Riparian forest buffer	0-3	B/D		63		56	59	48	37	1
Use exclusion/stream protection	8-15	B	82			76	33		-78	1
	8-15	C	82			76	33		-78	1
Vegetated filter strip	3-8	C	31		-3	35	-82	38	37	3
	3-8	D	95	90	71		68	73		1
	8-15	C	87		-20	63	-36	34	64	1
Vegetative filter strip (4.6-m)	3-8	C	83		69	85	72	74	84	1
	8-15	C	86		-83	73	2	57	73	1
	15-25	C	65		-50	51	5	-6	58	2
Vegetative filter strip (6.1-m)	3-8	C			55	42		48	37	2
Vegetative filter strip (9.1-m)	3-8	C	76		40	53	-43	37	45	2
	8-15	C	97		39	87	41	79	87	2
	15-25	C	79		-41	61	20	4	66	2
Waste storage facility	3-8	B				27			29	1
Watering facility	8-15	B	38			-10	41		-27	1
	8-15	C	38			-10	41		-27	2
Winter cover crop	0-3	D	91		37		75	37		3

[a]Hydrologic Soil-Group.
[b]Abbreviations of pollutants are as follows: T Sed = Total Sediment, PP = Particulate Phosphorus, DP = Dissolved Phosphorus, TP = Total Phosphorus, NO3-N = Nitrate Nitrogen, NH4-N = Ammonium Nitrogen, and TN = Total Nitrogen.
[c]Number of literature references for each BMP for the given conditions.
[d]Negative Values indicate a decrease in BMP effectiveness.