doi:10.2489/jswc.74.6.554

Using the Conservation Practice Effectiveness (CoPE) Database to assess adoption tradeoffs

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Abstract:. The newly published Conservation Practice Effectiveness (CoPE) Database compiles information on the effectiveness of a suite of conservation practices developed to treat contaminants in surface runoff and tile drainage water from agricultural landscapes. Traditional conservation practices such as no-tillage and conservation crop rotation are included in the CoPE Database, as well as novel practices such as drainage water management, blind inlets, and denitrification bioreactors. This will be particularly useful to conservation planners seeking new approaches to water quality problems associated with dissolved constituents, such as nitrate (NO_3) or soluble phosphorus (SP), and for researchers seeking to understand the circumstances in which such practices are most effective. Another novel feature of the database is the presentation of information on how individual conservation practices impact multiple water quality concerns. This information will be critical to enabling conservationists and policy makers to avoid (or at least be aware of) undesirable tradeoffs, whereby great efforts are made to improve water quality related to one resource concern (e.g., sediment) but exacerbate problems related to other concerns (e.g., NO_3 or SP). Finally, we note that the CoPE Database can serve as a source of the soft data needed to calibrate simulation models assessing the potential water quality tradeoffs of conservation practices, including those that are still being developed.

Key words: conservation effectiveness—conservation practices—nitrogen—nutrient management—phosphorus—water quality

Without nurturing our land and adopting proven soil and water conservation practices, it will not be possible to maintain the productivity levels needed to feed the additional billions of people the world is expected to have by 2050 (Delgado et al. 2011; FAO 2017). Agricultural production can impact downstream water quality with the magnitude and timing affected by practices such as tillage, crop rotation, and fertilizer use (Kanwar et al. 1997). To minimize adverse impacts, conservation practices have been developed and utilized for decades, with the costs underwritten by both public (e.g., national or local government) and private (e.g., philanthropic) sources. Given the tension between funding conservation versus other societal needs, and the increasing costs of mandatory funding relative to discretionary funding in federal budgets, it is now more important than ever to ensure that conservation practices deliver the expected environmental benefits. Thus, assessments of both individual practice effectiveness and comparisons of effectiveness across multiple practices are critical to guiding conservation investments. Data on conservation practice performance are present in the literature, but few conservation planners have time to fully explore these studies. The lack of readily accessible information on innovative practices can lead to overreliance on well-known practices (which may have limited value for the resource of concern) and missed opportunities to address resource concerns in ways that are more effective. A further challenge for conservation planners is that the effectiveness of conservation practices for various resource concerns is highly variable within and across field locations and years, and between plot and watershed scales, making it difficult for nonexperts to draw conclusions about practice effectiveness. Modelers face the same challenge: load estimates based on modeling results often overlook the high degree of uncertainty (Harmel et al. 2006a, 2014). According to Baker et al. (2018), "Having information from both the edge-of-field and small watershed scale would enable determination of field-scale nutrient and sediment mass balances, allowing a more accurate estimate of nutrient retention by conservation practices and nutrient loss to downstream waters." While the Measured Annual Nutrient loads from Agricultural Environments (MANAGE) Database (Harmel et al. 2006b, 2016) includes nitrogen (N) and phosphorus (P) runoff data from most of the published studies on agricultural fields as well as data on N and P loss in drainage water, it does not focus on conservation practice effectiveness. Compiling data across locations, timeframes, and spatial scales can also aid researchers in understanding the conditions under which conservation practices work well and where they work poorly or not at all.

Historically, conservation efforts in the United States have tended to focus on highly visible resource concerns that impact farm productivity, such as erosion (and the associated downstream sediment pollution). Many conservation practices have been designed specifically to address erosion and sediment loss from agricultural fields (e.g., grassed waterways and no-tillage). When erosion is the primary resource concern, these conservation practices are often the "go-to" strategies recommended by conservation action agencies and adopted by row crop producers. However, if other resource concerns exist, such as nitrate (NO_3) loss via tile drainage to surface water, then these erosion-based conservation practices are unlikely to beneficially impact these additional resource concerns. This is because these two conservation practices are designed to control off-site transport of soil particles, whereas NO_3 moving to and through tile drainage networks is dissolved in flowing water.

Focusing on a single resource concern and/or assuming that a practice designed to address a specific resource concern, such

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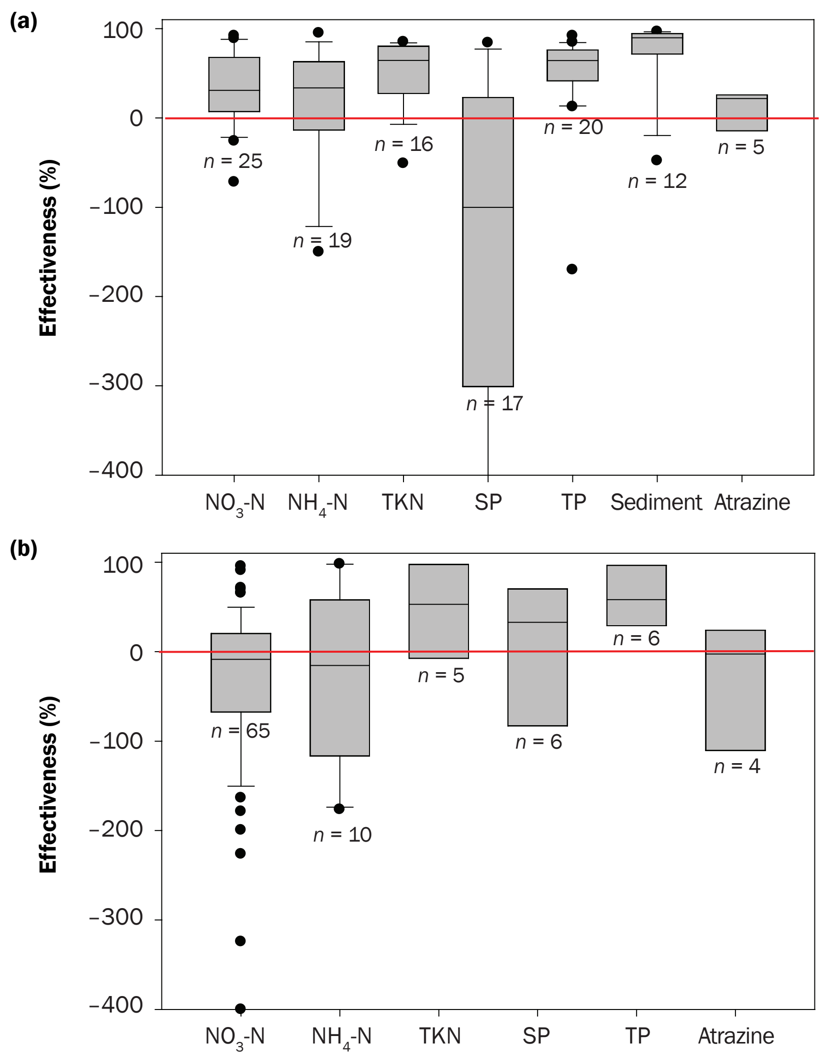
Figure 1

Practice effectiveness of no-tillage in (a) surface runoff and (b) tile drainage for nitrate (NO_3-N), ammonium (NH_4-N), total Kjehldahl nitrogen (TKN), soluble phosphorus (SP), total P (TP), sediment, and atrazine. Solid red bar represents 0% effectiveness; "*n*" indicates the number for comparisons represented by the box plot for a given constituent; black line within each box indicates the median value.



as erosion, will also address all other resource concerns, such as soluble nutrients, introduces risk. This is seen in the "law of unintended consequences" (Smith et al. 2015b). A focus on reducing erosion and particulate P losses at the farm level may inadvertently exacerbate downstream losses of soluble P (SP; includes soluble reactive P and dissolved reactive P). Conversely, addressing local stakeholder concerns about P-triggered impacts in fresh waters may inadvertently increase N losses, which impact downstream stakeholders in estuaries and other N-limited systems. Most conservation practices tend to focus on specific resource concerns with little regard for tradeoffs among other concerns (Tomer and Locke 2011), and the practice chosen to achieve a conservation objective may exacerbate problems associated with another resource concern (Klapwijk et al. 2014). Therefore, conservation planners need information about how a specific conservation practice will impact multiple resource concerns, so that tradeoffs can be anticipated and managed.

Natural resource model users also need data with which to calibrate and validate predictions. Models can be calibrated using monitoring data from outside the time or space of the simulated watershed of interest, a process typically referred to as soft calibration (Arnold et al. 2015). Soft data calibration is becoming an important aspect of calibrating natural resource models when there is insufficient local data available to fully calibrate and validate them. Increasingly, conservationists and policy makers want to know the potential impact of novel conservation practices prior to sufficient data collection that would allow for fully developed algorithms or routines to represent them in the process-based natural resource models. Thus, soft data calibration may be an important method by which this can be accomplished.

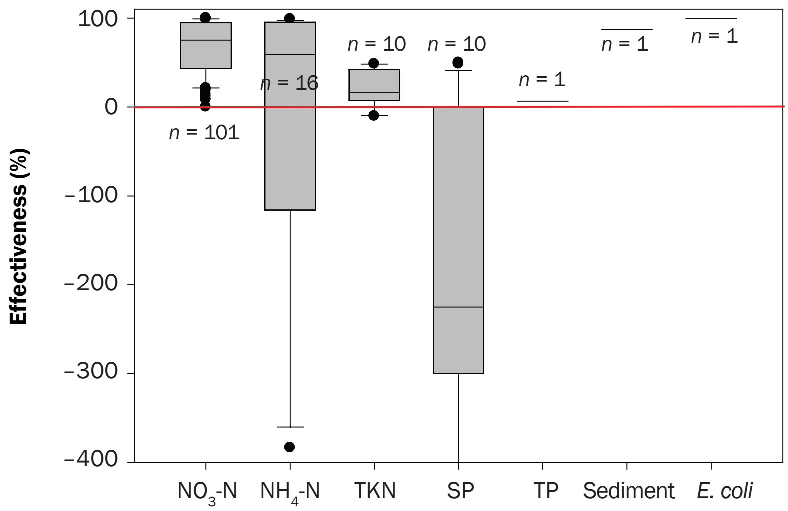
To better evaluate the uncertainty and variability of conservation practice effectiveness, data from multiple sources should be grouped and analyzed in aggregate. Based on the needs of (1) conservation planners to identify effective practices and manage tradeoffs between resource concerns, and (2) modelers to soft calibrate natural resource models, a Conservation Practice Effectiveness (CoPE) Database was developed from an extensive literature survey.

Materials and Methods

Data Compilation. Practice data were collected from published international literature on a variety of accepted conservation practices (i.e., conservation crop rotation, constructed wetlands, cover crops, grassed waterways, vegetative filter strips, manure amendments, no-tillage, and riparian buffers) and novel conservation practices (i.e., bioreactors, blind inlet, drainage water management, two-stage ditches, and stream modifications). The CoPE Database is currently stored in Microsoft Excel (Microsoft, Redmond, Washington) with data from each individual practice in its own spreadsheet, and can be found on a USDA Agricultural Research Service (ARS) website (USDA ARS 2019). There are currently 119 publications of the effects of conservation practices in the CoPE Database, containing more than 1,700 observations (USDA ARS 2019). Thus far, data from 24 US states, Canada, Ireland, New Zealand, Sweden, the Czech Republic, Germany, Spain, Netherlands, and United Kingdom are represented in the CoPE Database. There are currently 20 land uses represented in the database, including cash crops (i.e., corn [*Zea mays* L.], soybean [*Glycine max* L.], spring wheat [*Triticum aestivum* L.], etc.), forages (i.e., alfalfa [*Medicago sativa* L.], fescue, Bermuda grass [*Cynodon dactylon* L.], etc.), as well as feedlots, parking lots, and riparian areas. Each observation could be from a single runoff event to an annual

Figure 2

Practice effectiveness of tile drainage bioreactors for nitrate (NO_3-N), ammonium (NH_4-N), total Kjehldahl nitrogen (TKN), soluble phosphorus (SP), total P (TP), sediment, and *E. coli*. Solid red bar represents 0% effectiveness; "*n*" indicates the number for comparisons represented by the box plot for a given constituent; black line within each box indicates the median value.



load for either the conservation treatment or untreated condition. Observations were from plot, field, or small watershed scale grouped by conservation practice. In cases such as stream modifications, the observations were from upstream and downstream with the impact of treatment being the response once water flowed through the modified stream segment. Because the goal of this database is to provide information about the impact of conservation practices for use in modeling, model estimates of conservation practice effectiveness were not included.

Metadata captured by the CoPE Database include how large the study area is, the location of the study (city or county and state or province), crop rotation, current crop, soil (including soil taxonomy), study duration, and whether the study was the result of natural rainfall or rainfall simulations. Ancillary information about soil test (i.e., soil N or P concentrations) was also captured when available. The publication associated with each data set is referenced, and a detailed bibliography is also included. The goal is to update the database every 12 to 18 months, or as data and sources become available for emerging technologies that can be used to decrease nutrient losses from agricultural sources. It is anticipated that users of the CoPE Database will wish to select practices, for example by region, plot size, study period length, and so on, to suit their own purposes.

For each observation, at least one chemical constituent was measured, but often several constituents were included (e.g., NO_3-N, ammonium-N [NH_4-N], total Kjeldahal N (TKN), total N (TN), SP, total P (TP), sediment, atrazine, glyphosate, and *E. coli*) and reported. Both constituent loads and concentrations were recorded if reported. A conservation practice effectiveness was calculated when a constituent was reported for both the treated and control condition over the same duration (i.e., for the same year). This was accomplished by subtracting the treated condition load (or concentration if load not available) from the untreated and then dividing by the untreated. Thus, positive values indicate that the conservation practice is "removing" the constituent, whereas negative values indicate that there were higher values for the constituent in the treated condition compared to the untreated. There are more than 2,100 individual conservation practice efficiencies in the CoPE Database to date.

Results and Discussion

In this section, a summary of the practice effectiveness calculated in the CoPE Database is presented for five conservation practices. This summary is meant to present the breadth of the data currently available through the database.

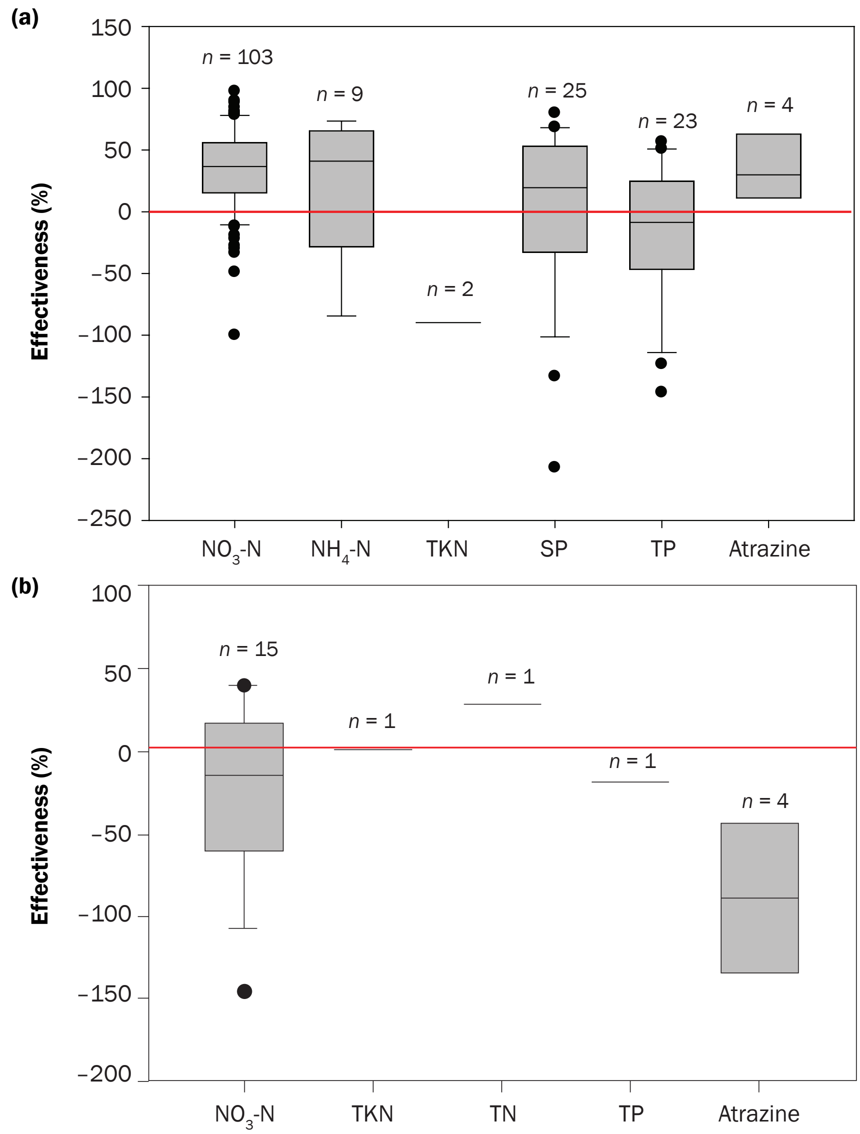
Figure 1 represents the conservation practice effectiveness of no-tillage for surface runoff (figure 1a) and tile drainage (figure 1b). While no-tillage is one of the most studied conservation practices, it was included in the database for two primary reasons. First, since there is so much work assessing the impact of no-tillage, this practice makes an excellent test case for the CoPE Database to ensure we are able to capture and report all the data fields necessary. Second, no-tillage was designed to minimize sediment loss from surface runoff in fields. Recent studies have examined the impact of no-tillage on soluble nutrient concentrations in surface runoff as well as soluble and total nutrients loads in tile drained fields. In fact, widespread adoption of no-tillage has been implicated as one potential cause of increased SP loading to Lake Erie and the concomitant algal blooms (Smith et al. 2015a; Jarvie et al. 2017), contrary to reports of its early successes within the basin (Richards et al. 2009). Further reports have indicated that it is not necessarily the practice of no-tillage itself that is the problem, but failure to adaptively manage fertility once no-tillage is adopted (Smith et al. 2018).

The impact of no-tillage on surface runoff is largely positive based on the calculated conservation practice effectiveness for several forms of N, TP, sediment, and atrazine (figure 1). However, no-tillage may negatively impact SP losses in surface runoff. With 17 comparisons for SP practice effectiveness, a wide range in values was observed, with a mean value of −139% and a median value of −100%. The tradeoff between sediment (and sediment-bound nutrients) and soluble nutrients has been documented since Sharpley et al. (1991) and Smith et al. (1991) reported no-tillage increased SP loads compared to tilled fields in Oklahoma.

It has been well documented that tile drainage is a predominant pathway for NO_3-N losses from fields. Interestingly, while no-tillage was designed to address surface runoff issues, there are more data available on NO_3-N in drainage water (n = 65) than surface runoff (n = 25). It is also interesting to note that this practice has positive conservation practice effectiveness for TKN, SP, and TP based on the available data (figure 1b). The impacts on NH_4-N and atrazine are neutral, as is the no-tillage practice effectiveness for NO_3-N in tile drainage, despite a wide range in reported values. This range in reported results could stimulate researchers to work to better understand the causes of the variability in practice effectiveness.

Figure 3

Practice effectiveness of drainage water management in (a) tile drainage and (b) surface runoff for nitrate (NO_3-N), ammonium (NH_4-N), total Kjehldahl nitrogen (TKN), total N (TN), soluble phosphorus (SP), total P (TP), and atrazine. Solid red bar represents 0% effectiveness; "*n*" indicates the number for comparisons represented by the box plot for a given constituent; black line within each box indicates the median value.



Since tile drainage is known to be a major pathway for NO_3-N loss, denitrification bioreactors have been developed to address this resource concern. Figure 2 presents conservation practice effectiveness of bioreactors for tile drains. Not surprisingly, the preponderance of information on this practice relates to NO_3-N loss, which overwhelmingly shows this to be an effective practice to reduce NO_3-N loss via this pathway. There is considerably less information available to evaluate the practice effectiveness of bioreactors for other contaminants; however, it appears to be neutral for TKN and mostly positive for NH_4-N. Soluble P losses may increase from the use of bioreactors, possibly due to release from woodchips under anaerobic conditions. There are few reports of TP, sediment, and *E. coli* effectiveness when bioreactors are used.

Drainage water management is another practice often promoted to reduce NO_3-N loadings via tiles. There is a considerable amount of information collected from the 18 published studies on this practice. By and large, tile drainage losses of NO_3-N, NH_4-N, SP, and atrazine appear to decrease as a result of drainage water management, while the impact of this practice on TP appears to be neutral (figure 3a). Few studies evaluate the impact of drainage water management on surface runoff losses, with only one comparison each for TKN, TN, and TP (figure 3b). There are slightly negative impacts of drainage water management on surface runoff in terms of NO_3-N loss, and based on the four comparisons available in the literature, the impact of drainage water management on atrazine losses in surface runoff also appears to be negative.

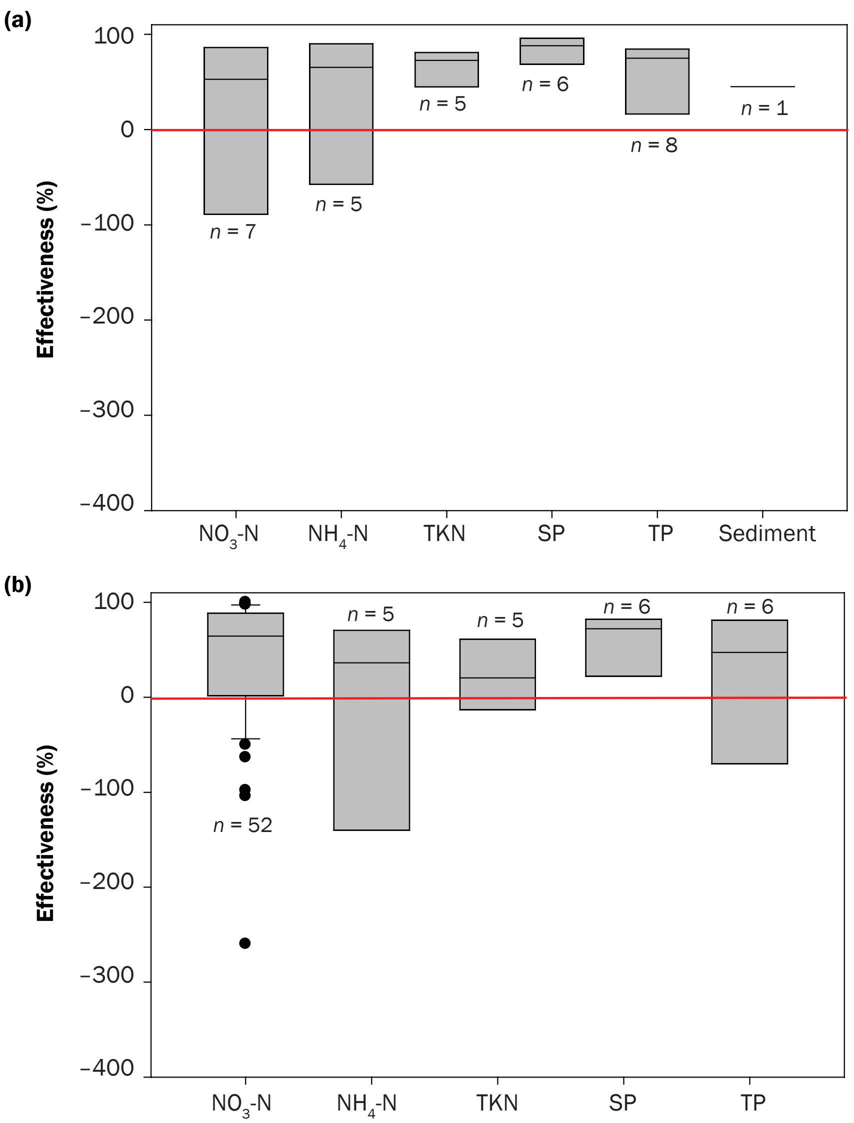
Conservation crop rotation is a practice promoted by the USDA Natural Resources Conservation Service (NRCS) and other conservation action agencies to include more than just one or two crops in the rotation. Based on eight published reports in the literature, this practice appears to have largely positive effectiveness for NO_3-N, NH_4-N, TKN, SP, and TP in surface runoff (figure 4a). While there are often tradeoffs between surface and subsurface flows, the conservation practice effectiveness for increasing the number of crops in the rotation appears to also be positive for N and P constituents (figure 4b). While there are no "silver bullets" that will improve all natural resource concerns, this practice may hold more benefit than some others that have been widely adopted by producers.

Cover crops are being promoted by conservation action agencies to address multiple natural resource concerns. Conservation practice effectiveness for cover crops are calculated for NO_3-N, NH_4-N, SP, TP, and atrazine in surface runoff (figure 5a), and NO_3-N and atrazine in tile drainage (figure 5b). Proponents of this practice are largely interested in controlling sediment and NO_3-N losses. Of the nine studies in the CoPE Database that report on cover crops, none provide information on sediment in runoff or tile drainage. However, there is sufficient information to provide 23 effectiveness calculations for NO_3-N in surface runoff and 70 effectiveness calculations in tile drainage. This is sufficient information to recommend with confidence that in most circumstances, cover crops will have a positive impact for reducing NO_3-N losses.

While our discussion thus far has focused on the value of the CoPE Database for understanding the impact of individual conservation practices, we suggest that the database can also be used to identify suites

Figure 4

Practice effectiveness of conservation crop rotation in (a) surface runoff and (b) tile drainage for nitrate (NO_3-N), ammonium (NH_4-N), total Kjehldahl nitrogen (TKN), soluble phosphorus (SP), total P (TP), and sediment. Solid red bar represents 0% effectiveness; "*n*" indicates the number for comparisons represented by the box plot for a given constituent; black line within each box indicates the median value.



of conservation practices implemented across the landscape to successfully address multiple resource concerns, thereby minimizing the risk of tradeoffs. For example, suppose that for an individual field or farm, the primary resource concern is erosion. Our database can be used to identify those practices best-suited to minimizing losses of sediment and particulate P. However, as these practices may increase the losses of SP, a conservation planner could consider identifying a set of practices that are effective in treating this resource concern and implementing these downstream to intercept agricultural drainage water from the farm. Further recognizing that erosion control practices, such as no-tillage, may exacerbate N losses, the planner could opt to include additional practices that are effective in removing NO_3-N from agricultural drainage water. Used in this way, the CoPE Database serves as a menu of options from which a planner could develop a "treatment train" of practices (Lien and Magner 2017; McLellan et al. 2018) at the watershed scale to manage multiple resource concerns and minimize or even avoid water quality tradeoffs.

Summary and Conclusions

Adoption of conservation practices is essential to ensure agricultural producers minimize environmental footprint and provide a growing population with food, fiber, feed, and fuel in a sustainable manner. Here, we present a database of conservation practice effectiveness that can be used by researchers, conservationists, and policy makers to determine the potential impact of conservation practices on water quality. The CoPE Database also provides important information to modelers to ensure natural resource models appropriately predict the impact of conservation practices, especially in landscapes or from conservation practices for which there is insufficient information to perform a full calibration.

Availability

The CoPE Database is available in the Ag Data Commons with the National Agricultural Library. The DOI for the database is 10.15482/USDA.ADC/1504544.

Acknowledgements

Support for this research was provided in part by Environmental Defense Fund. The USDA is an equal opportunity provider and employer.

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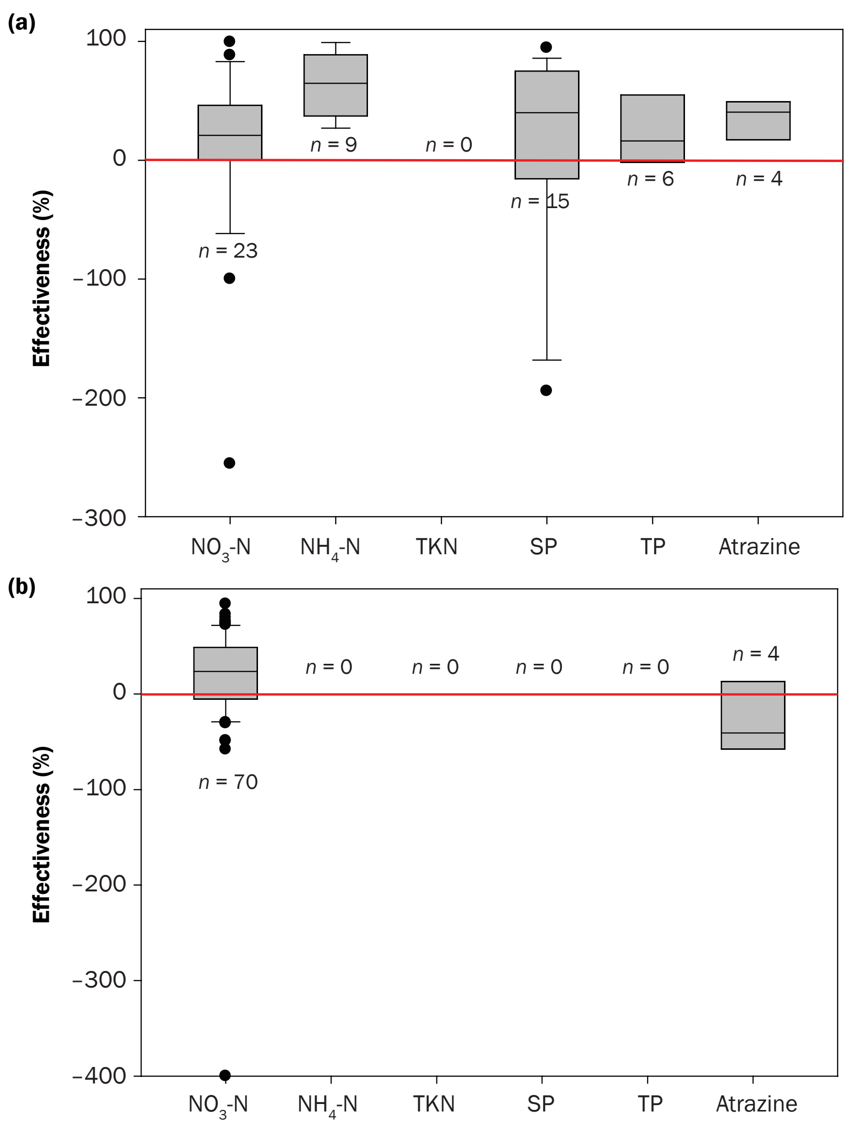
Figure 5

Practice effectiveness of cover crops in (a) surface runoff and (b) tile drainage for nitrate (NO_3-N), ammonium (NH_4-N), total Kjehldahl nitrogen (TKN), soluble phosphorus (SP), total P (TP), and atrazine. Solid red bar represents 0% effectiveness; "*n*" indicates the number for comparisons represented by the box plot for a given constituent; black line within each box indicates the median value.



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