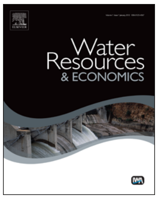
Water Resources and Economics 15 (2016) 43–56

Contents lists available at ScienceDirect

Water Resources and Economics

journal homepage: www.elsevier.com/locate/wre



How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin?

Sarah S. Roley [a,*], Jennifer L. Tank [a], John C. Tyndall [b], Jonathan D. Witter [c]

[a] *Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA*
[b] *Department of Natural Resources Ecology and Management, Iowa State University, Ames, IA 50011, USA*
[c] *Agricultural and Engineering Technologies, Ohio State Agricultural Technical Institute, Wooster, OH 44691 USA*

ARTICLE INFO

Article history:
Received 30 October 2015
Received in revised form
17 June 2016
Accepted 20 June 2016

Keywords:
Water quality economics
Nutrients
Eutrophication
Conservation practices
Two-stage ditch
Wetlands
Cover crops

ABSTRACT

Excess nitrogen (N) causes numerous water quality problems, and in the upper Mississippi River Basin, much of the excess N results from landscape modifications necessary for row crop agriculture. Several conservation practices reduce N export, but cost estimates for these practices are often lacking, which can inhibit decisions by farmers and policy-makers. Many practices are eligible for cost-share funds from the United States Department of Agriculture (USDA), but these programs do not usually cover the full cost, and so farmers need to be able to approximate their share of costs. In addition, cost estimates may help the USDA to set priorities and make programmatic decisions. We address lack of cost information by estimating the direct implementation costs and USDA program costs for three agricultural conservation practices: wetlands, cover crops, and two-stage ditches, over 10 and 50 year time horizons. We then compare these costs to the N removal effectiveness of each practice, in $ kg N^{-1} removed. Wetlands were the most cost-effective practice (in $ kg N^{-1} removed) over both time horizons. Over 50 years, the two-stage ditch ranked second in cost-effectiveness and cover crops were least cost-effective, while over 10 years, cover crops were second and two-stage ditches were least cost-effective. Finally, we note that these practices need not be used in isolation, but can be implemented simultaneously to maximize N removal. Overall, our analysis suggests that careful implementation can cost-effectively mitigate N pollution.

1. Introduction

Excess nitrogen (N) is a problematic pollutant in freshwater and coastal ecosystems worldwide [1], and it can contaminate drinking water [2], decrease biodiversity [3], and cause coastal hypoxia [4]. In the Gulf of Mexico, most of the excess N originates from the upper Mississippi River Basin [5], especially in the Corn Belt where row-crop agriculture is the predominant land use [6]. In typical row-crop agriculture in the Corn Belt, N fertilizers are added annually to improve crop growth, and fields are artificially drained to keep the root zone aerated. Artificial drainage includes sub-surface tile drains and channelized streams and ditches, which often receive tile drain inputs [7]. These landscape modifications optimize crop yields, but also facilitate the export of excess N to downstream water bodies [8,9]. In an effort to maintain yields and minimize costly ecosystem impairments caused by nutrient transport, states throughout the Mississippi River Basin have developed nutrient reduction strategies [10], which focus on the widespread voluntary adoption of effective, nutrient-reducing, conservation practices (e.g., [11]).

These nutrient reduction strategies incur large

---

[*] Corresponding author. Current address: WK Kellogg Biological Station, 3700 E Gull Lake Dr, Hickory Corners, MI 49060, USA.
E-mail address: roleysar@msu.edu (S.S. Roley).

http://dx.doi.org/10.1016/j.wre.2016.06.003
2212-4284/

economic costs, as do the consequences of N pollution [12–14]. As a result, several studies have examined how to mitigate N pollution, while minimizing costs. Macroeconomic studies have examined the large-scale effects of basin-wide management, including extensive wetland restoration and mandatory reductions in fertilizer application rates [15,16]. These analyses have provided important insights into the economic and social welfare consequences of large-scale N management. They demonstrated that mandatory fertilizer reduction was the most cost-effective option for reaching modest N-reduction goals in the Mississippi River Basin, but wetlands restoration was preferable for achieving more ambitious N-reduction goals [15,16]. Others have quantified N-reduction costs within small geographic areas, which allows for exploration of relationships between biophysical function and economic outcomes, providing estimates of the cost of various management strategies to remove a unit of N [17,18].

These management strategies involve the implementation of conservation practices, which are typically either cultural or structural in nature [19]. As described in Tyndall and Roesch [20], cultural practices include in-field practices that minimize erosion or nutrient transport, such as cover crops, nutrient management, and conservation tillage. Structural practices involve natural or artificial structures that are placed within or at field edges and often feature perennial vegetation and/or landform engineering. Structural practices are designed to capture or treat sediment and nutrient runoff, reducing delivery to downstream water bodies. In order to be used effectively, conservation practices must be: 1) bio-physically effective; 2) compatible with the landscape context and farming system; and 3) financially practicable – that is, they must be affordable and cost-effective [20].

There are often a number of pragmatic economic unknowns in the usage of conservation practices, and this financial uncertainty can be a barrier to implementation [17,21]. Specific and up-to-date cost estimates are lacking for many practices, which make it difficult for farmers to determine if a practice is affordable (in general or relative to alternative practices). Also, although the N-removal potential of most practices has been variously documented, their differing biophysical structures and costs make comparisons problematic for cost-effectiveness analysis. Cost-effectiveness analysis identifies the least cost method for meeting a specific physical outcome, for this study it is simply the reduction of 1 kg of transportable N. Finally, financial incentives, such as cost-share or rental payments, are often critical in the adoption process for many farmers [22]. Such funding is often contingent upon its disbursement being used efficiently in both economic and biophysical contexts. Unfortunately and critically, very little information exists that allows agencies such as the USDA Natural Resource Conservation Service (NRCS) or Farm Service Agency (FSA) to assess the relative effect of their financial programming on reducing the monetary burden on participating landowners. The purpose of this study is therefore three-fold: 1) to estimate the direct implementation cost for three different N-reducing conservation practices; 2) compare these costs to existing USDA cost-share programs; and 3) determine comparative measures of cost-effectiveness in terms of $ kg N^{-1} removed. For this study we examine one in-field cultural practice, cover crops, and two edge-of-field/waterway structural practices: wetland restoration and two-stage ditch construction.

Cover crops (e.g. annual and cereal ryegrass, wheat, oat, forage radish) can reduce N leaching by immobilizing N during the winter, when fields are otherwise devoid of vegetation and thus prone to N losses [23]. Cover crops are planted after the fall harvest (or inter-seeded at the end of the growing season), and grow and incorporate nutrients during the winter when fields are normally fallow [24]. In the spring, cover crops have either self-terminated over winter, or are actively terminated with an herbicide or by mechanical means (e.g. crimping, rolling, cutting), or plowed under prior to planting of the production crop. In addition to their prevention of soil N leaching, cover crops can also help to minimize soil erosion, improve soil quality, and enhance habitat [24–26].

Wetlands and two-stage ditches both capture field runoff and promote N processing and removal prior to its export downstream [27,28]. For both, N removal occurs through assimilatory uptake into biomass and via microbially-mediated denitrification into N gasses. Nevertheless, key aspects of their landscape placement and hydrology make wetlands and two-stage ditches distinct practices. Restored wetlands are designed to receive N-rich water from tile drain outlets or small ditches, and they hold and process the water before it discharges to a larger surface water outlet [27]. Wetland sediments are typically anoxic and rich in organic matter, which promotes denitrification [27,29]. Importantly, wetlands are generally most effective under base flow conditions, when water flow into wetlands is slow enough to be retained [30].

In contrast, two-stage ditches were originally developed to address the instability of stream banks in conventional, trapezoid-shaped ditches [31], which are channelized to move water downstream quickly. As such, conventional agricultural ditches and streams typically have steep banks, which often fail during high flows, depositing sediment within the channel [32]. This unsustainable morphology requires regular channel dredging to maintain drainage capacity, which minimizes biological N processing and removal. In a two-stage ditch, floodplains are constructed adjacent to the incised channel. During times of high discharge, water flows onto the floodplains, which reduces water velocity and shear stress, and the ditch remains stable, eliminating the need for periodic dredging [33]. In addition, the two-stage ditch increases water residence time and stream surface area, providing more time and space for N removal processes such as denitrification [28].

As a key complementary practice to both wetlands and two-stage ditches, grass buffer strips are uncultivated zones adjacent to the field and the wetland edge or ditch, and they are intended to serve as a transition area between row crops and the ditches or streams, and can reduce surface erosion and nutrient inputs to adjacent waterways. Grass buffer strips stand alone as a conservation practice (e.g., Vegetative Filter Strip, NRCS Practice Code