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Conservation dairy farming impact on water quality in a karst watershed in northeastern US

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ABSTRACT

One crucial challenge of agriculture is to increase productivity to feed the continuously growing population without deteriorating soil, water, and environmental quality. More emphasis on improved efficiencies, appropriate management of agricultural systems, and improved agronomic and nutrient use practices are needed to address this challenge. A conservation dairy farming system that produces the majority of the dairy feed and forage crops, with no-till, continuous diversified plant cover, and manure injection has recently been developed and tested in Pennsylvania, but the effect of this newly developed cropping system on nonpoint source pollution at the watershed scale is yet to be investigated. Topo-SWAT, a variation of the Soil and Water Assessment Tool (SWAT), was used to simulate nutrient and sediment loading processes of four dairy farming scenarios that differed in land area and implemented different feed production and nutrient input strategies: (i) forage crop production only and no best management practice (no-BMP scenario); (ii) forage production only and typical Pennsylvania management, which includes some no-till and cover cropping (typical scenario); (iii) forage and feed crop production with conservation management with broadcast manure (conservation-BM scenario); and (iv) forage and feed crop production with conservation management with injected manure (conservation-IM scenario). The conservation-IM scenario was the most effective for reducing total nutrient (42% N and 51% P) and sediment (41%) load in the watershed. The typical scenario also reduced nutrient and sediment load compared to the no-BMP scenario. Both conservation scenarios significantly reduced the number of in-stream peaks of organic N (73–82%), nitrate-N (43–47%), organic P (41–50%), and soluble P (62–70%) concentration compared to the typical scenario. Introduction of manure injection hindered runoff-mediated loss of nutrients but not leaching. Both conservation scenarios also decreased nitrous oxide emission by reducing denitrification. Additionally, manure injection retarded 91% of the N volatilization that occurred in manure broadcast scenario. The watershed scale study indicates that implementation of the conservation scenarios can largely contribute to the initiatives of achieving a target total maximum daily load in the Chesapeake Bay.

1. Introduction

Increasing agricultural productivity to feed the growing population without deteriorating soil, water and environmental quality is a critical need we face today. Agriculture remains a major cause of nonpoint source pollution of nitrogen (N), phosphorus (P), and sediment (Horowitz et al., 2009). These nonpoint source pollutants join streams through overland flow and/or leaching and groundwater-surface water interactions and finally end up in the coastal water. For example, 34% of total N, 50% of total P, and 52% of total suspended solids entering the Chesapeake Bay originate from agricultural land (CBP, 2016). To meet the target total maximum daily load (TMDL) of the Chesapeake Bay for 2025 set by the Chesapeake Bay Program (Shenk and Linker, 2013; CBP, 2016), loadings of N, P, and sediment from agricultural land of the watershed need to be reduced by 25–30%. Similar situations exist throughout the world. Contaminants joining groundwater often appear in abstraction wells located miles away from the pollution source because large public water supply wells can have a large area of influence (US EPA, 2004; Giacomoni et al., 2014). The agricultural sector is also a source of several primary greenhouse gases, such as CO_2, CH_4, and N_2O (Crosson et al., 2011). To address these challenges in an environmentally and economically sustainable manner using current production systems and technologies, agriculture needs to place more emphasis on appropriate management of agricultural systems, and

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improved agronomic, nutrient use practices and efficiencies (Smith et al., 2007).

Dairy farming is one of the largest agricultural sectors in the northeastern United States (USDA ERS, 2016). Many of the dairy farms are small to mid-sized family farms that produce much of their required forage and some grains (Winsten et al., 2010). The dairy farms run on many external inputs, i.e. fossil fuel, fertilizer, herbicides, and pesticides, which exert significant environmental impacts on air and water quality (Cruse et al., 2010; Woodhouse, 2010; Davis et al., 2012). This industry has experienced tremendous financial stress and undergone dramatic shifts in the past several decades (Winsten et al., 2010). As United States dairy herd sizes increase in size (MacDonald and McBride, 2009), farms typically import more feed, and the increased quantity of manure nutrients relative to the cropland has contributed to soil nutrient loading (Bacon et al., 1990; Klausner et al., 1998; Ribaudo et al., 2003). Off-farm feed costs often account for significant dairy farm costs (Ghebremichael et al., 2009) and fluctuate with changes in feed and fuel markets. For instance, from 2010 to 2016, off-farm feed accounted for more than half of the feed costs for an average Pennsylvania dairy farm (USDA ERS, 2016). Consistently yielding sufficient net income to adequately support the farm family becomes a fundamental issue. Von Keyserlingk et al. (2013) concluded that the current structure of the dairy industry lacks the resilience to adapt to changing social and environmental landscapes.

To promote sustainable dairy production, profitability, and reduce environmental impacts, the Northeast Sustainable Agriculture Research and Education (NESARE) Dairy Cropping System project at the Pennsylvania State University developed a diversified conservation dairy cropping system. It was designed to produce all of the forage and feed crops for a typical 65-cow milking dairy cattle herd on farm of 97 ha. Two, six-year no-till crop rotations that include continuous cover with perennials, and summer and winter annual crops; and manure injection were evaluated with farm-scale equipment at the Pennsylvania State University Agronomy Research Farm in northeastern United States (Snyder et al., 2016a; Snyder et al., 2016b; Malcolm et al., 2015). This conservation dairy cropping system has potential to produce all of the forage and feed needs and minimize the needs of off-farm inputs and environmental impacts, but some management practices of this dairy cropping system may have unanticipated environmental impacts in different agro-hydrological conditions. For example, manure injection can influence leaching and denitrification loss of N variably under different application conditions (Weslien et al., 1998; Powell et al., 2011; Dell et al., 2012). Thus, the effect of the diversified conservation dairy cropping practices on nonpoint source pollution at the watershed scale is yet to be investigated.

Extrapolating plot-scale experimental results or long-term monitoring data for watershed management decision making may pose risks. Many uncertainties are involved in direct upscaling of field data to watershed scale because of complex diversity of soil types and land uses and complex soil-water-plant-atmosphere relationships (Hofstra and Bouwman, 2005). On the other hand, extensive replication studies over the watershed are very expensive and time consuming. Simulation models can be cost-effectively used to study watershed-scale results of an agricultural management decision. The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), a watershed scale model, is capable of simulating stream discharges and nutrient and sediment loads in a watershed under varying climatic and agricultural management conditions. The SWAT model and a Topo-SWAT variation have previously been used as an assessment tool for various agricultural management decisions in some watersheds (e.g., Kaini et al., 2012; Amin et al., 2017).

We hypothesized that by growing the majority of the dairy herd forage and feed crops and utilizing conservation practices, the conservation dairy cropping system will reduce nonpoint source pollution and soil erosion relative to “no-BMP” dairy farms (dairy farms using no best management practices) and to typical Pennsylvania dairy farms, which employ some no-till and cover cropping, but do not produce all of their feed and forage crops. This work provides information to understand some biological and nutrient transport processes and qualitatively compare simulation results of a watershed scale model with some field scale observations. Spring Creek watershed of Centre County, Pennsylvania was chosen in this study as a representative subwatershed of the Appalachian Ridge and Valley physiographic province of the upper Chesapeake Bay watershed. The specific objectives of the study were to: (i) investigate nutrient cycle dynamics and sediment transport processes at the farm scale as affected by the conservation dairy cropping practices; and (ii) simulate the effects of the conservation dairy cropping practices on nutrient and sediment loading in the Spring Creek watershed.

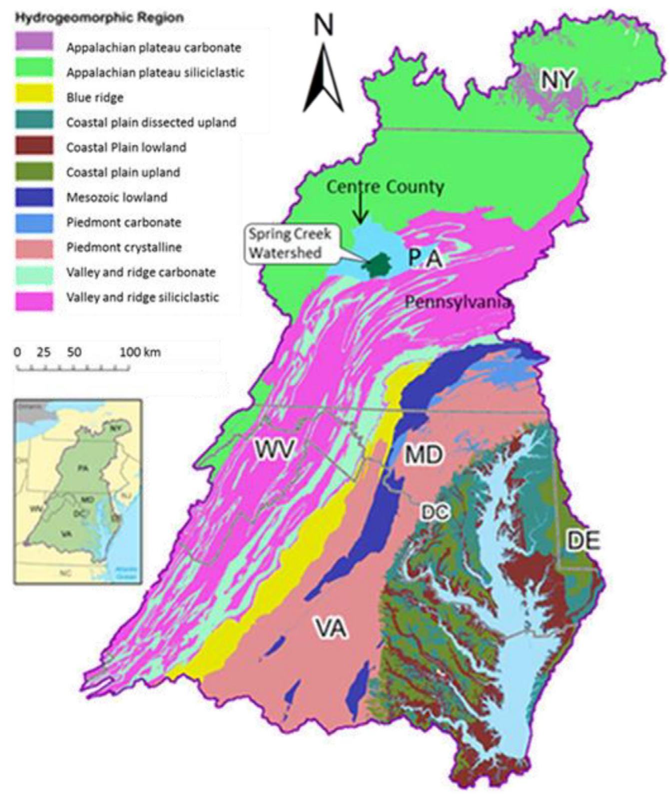

Fig. 1. Location map of Spring Creek watershed with the Chesapeake Bay watershed in northeastern USA (Source: United States Geological Survey and the ChesapeakeBay Program website http://www.chesapeakebay.net/maps/map/hydrogeomorphicregions).

2. Materials and methods

2.1. Study watershed

Spring Creek watershed, located within Centre County, Pennsylvania in northeastern USA (Fig. 1), drains an area of approximately 370 km^2 (40°40′– 40°59′ N and 77°38′ – 78°00′ W) into Bald Eagle Creek, a tributary to the West Branch Susquehanna River that drains to the Chesapeake Bay estuary. The watershed is situated at an elevation of approximately 370 m above mean sea level. Bald Eagle, Tussey, and Nittany Mountain ridges with reliefs of 180–305 m from the valley floor are the most prominent topographic features in the watershed. The climate is temperate with hot, humid summers and cold winters. The geologic formation in this watershed is of karst type (Buda and DeWalle, 2009; Piechnik et al., 2012; Brooks et al., 2011). Surface runoff during low flow periods provides the majority of the watershed's baseflow by infiltrating into fractures and sinkholes throughout the land surface and returning to the valley via limestone springs (Fulton