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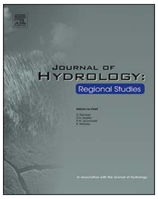

Topographic wetness guided dairy manure applications to reduce stream nutrient loads in Central New York, USA

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ABSTRACT

Study region: Fall Creek Watershed in central New York, USA.

Study focus: Dairy manure is commonly applied to NY, USA agricultural fields as both a crop nutrient source as well as a means of waste disposal. Managing excess manure places an economic burden on small farm operations due the prohibitive cost of existing practices and regional dominance of saturation-excess hydrology. Through a SWAT modeling exercise we evaluate the efficacy of dairy manure application following the topographic wetness index (TI) as a means of reducing non-point source agricultural nutrient runoff. Next, we examine the efficacy of amending dairy manure with chemical N as a means of reducing the rate of soil TDP accumulation.

New hydrological insights: We observed that application of manure to drier pastures results in less TDP and NO_X surface losses, but an undesirable increase soil TDP accumulation. Further, pastures receiving dairy manure are typically N limited during summer months, limiting plant P uptake. Manure N amendment reduced TDP accumulation and increases crop yield, but slightly increased NO_X surface losses. Spreading dairy manure based on the TI concept represents a feasible path towards reduction of agricultural non-point nutrient runoff, although management strategies need to consider ways to also reduce the long-term accumulation of soil P, which could have consequences in the future that are difficult to mitigate.

1. Introduction

Eutrophication is a growing chronic social, economic, and environmental concern. Considerable anthropogenic sources of nitrogen (N) and phosphorous (P) can result in unmitigated algal growth within streams, lakes, and coastal areas. Eutrophication often negatively impacts aquatic ecosystems, diminishes drinking water quality, contributes to human illness, and has lasting negative economic effects (Chislock et al., 2013). Recently, research has focused on the connection between eutrophication and nutrient cycling in headwater streams, specifically the importance of practices that co-manage both N and P (Dodds and Smith, 2016). Agricultural runoff has long been recognized as a significant non-point source of excess nutrients (e.g. Carpenter et al., 1998; Sharpley et al., 1994).

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Discussion of agricultural fertilizer and manure best management practices (BMPs) often involves a reduction of the total fertilizer (i.e. nutrient) load applied to agricultural fields (e.g. Jang et al., 2017; Durand et al., 2015; Liu et al., 2014, among others). These studies, while useful, tend to artificially frame the problem in a way that ignores economic realities. Dairy manure spreading on agricultural fields typically has the dual purpose of crop fertilization and waste disposal (Kleinman et al., 2015; Carpenter et al., 1998). While this current practice is non-ideal in that it may generate non-point pollution, disposal of dairy manure through other means is probably economically prohibitive for dairy farmers (Kleinman et al., 2015). Non-point control measures to recycle nutrients in runoff (e.g. Sharpley and Wang, 2014) may be similarly inapplicable in the case of dairy manure fertilization as the rate of N and P application commonly exceeds crop growth requirements.

Waste manure is of particular concern for dairy farm operations in central New York, USA (NY). Klausner et al. (1998) demonstrate that imported nutrients in NY dairy farm feed commonly creates an excess of nutrients required for plant growth within a farming operation. This practice upsets the nutrient mass balance of farming operations yielding a net export of nutrients. The hydrology of central NY watersheds is defined by a shallow confining layer which leads to a landscape dominated by saturation-excess runoff (Easton et al., 2007; Dahlke et al., 2009). Managed agricultural land within the saturated Variable Source Area (VSA) of central NY watersheds frequently generate overland runoff and stream nutrient loading due to consistently saturated soils and a moderately wet climate (Hofmeister et al., 2016). The spreading of excess dairy manure as a waste management practice (i.e. spreading in excess of crop nutrient requirements as a means of disposal) contributes to non-point P losses from NY dairy farms (Hively et al., 2005) and the long-term P enrichment of New York agricultural soils (Ketterings et al., 2005).

Giasson et al. (2003) demonstrate P management on NY dairy farms for water quality benefit relies on relatively expensive infrastructure such as manure storage facilities and precision temporal manure applications, which can be infeasible in the case of smaller farms (< 250 cows). Restrictions on nutrient runoff (i.e. fertilizer applications) have been shown to affect the financial viability of smaller operations, whereas larger operations were more capable of absorbing this economic loss (Schmit and Knoblauch, 1995). Poe et al. (2001) demonstrate through surveys that the willingness of NY dairy farmers to devote resources to environmental goals was negatively correlated with the cost of the management practice.

There are a variety of green-infrastructure-like tools available to watershed engineers to control agricultural runoff (e.g. vegetated swales, enhanced stream buffers, denitrifying bioreactors, constructed wetlands). We refer to green infrastructure (GI) as conservation and pollution mitigation strategies that utilize or enhance natural ecosystem services. There has been much research on the performance of watershed-wide GI installations in the control of non-point agricultural runoff (e.g. Chen et al., 2014; Durand et al., 2015). While structural GI projects may be a path towards agricultural pollution load reductions, they currently face several design limitations. First, GI practices must be sited at collection points of agricultural runoff and therefore rely on specific placement within the landscape (Chen et al., 2014). Buchanan et al. (2013a) demonstrate how road-side ditches within NY USA watersheds may serve as collection points of agricultural runoff; however, reliance on road-side ditch pollutant transport may not be a reliable nutrient load collection system in all engineering applications. Second, the nutrient removal efficiency of GI systems has varied considerably (e.g. Walter et al., 2015) with some installations contributing to downstream N and P loads (McPhillips et al., 2018). Finally, GI solutions attempt to control the problem at the outlet. It has long been proposed that the most effective measures for N and P non-point sources occur closest to the point of application (Sharpley et al., 1994).

There has been a growing discussion on the efficacy of spatially targeted fertilizer application to agricultural land as a means of reducing non-point source pollution. Watersheds are spatially varied ecosystems composed of land with diverse hydrological and ecological function and value (Walter et al., 2007). Beyond natural ecosystems, patterns within managed agricultural land tend to emerge with respect to soil nutrient concentration, plant uptake, and surface runoff (Peukert et al., 2016; Lerch et al., 2015; Carpenter et al., 1998). Walter et al. (2007) suggest that we may be best served through land conservation and management practices which explicitly consider these ecohydrologic sensitivities and patterns.

Recent research has demonstrated that watersheds in the Northeast US are spatially and temporally variable with respect to both surface runoff (Hofmeister et al., 2016; Buchanan et al., 2014; Cheng et al., 2014) and nutrient loading (Winchell et al., 2015; Collick et al., 2015; Buchanan et al., 2013b). Wesström et al. (2014) demonstrate that modification of the watershed hydrology through irrigation may have practical implications for controlling runoff and non-point pollution loading from agricultural land. Alternately, Thodsen et al. (2015) explore the concept of fertilizer redistribution to naturally hydrologically “low risk” and “high risk” areas for surface runoff generation. They demonstrate that some NO_3 runoff reduction can be achieved by targeting fertilizer application to farmland which is hydrologically drier and therefore contributes less to surface runoff.

Lerch et al. (2015) demonstrates that in the case of N, application in excess of crop requirements likely results in increased surface or groundwater N losses, and not necessarily an accumulation of N in the soil layers. Beyond surface runoff and groundwater leaching, N has several additional pathways out of the watershed in ammonia volatilization and denitrification. While N has the opportunity to volatize or denitrify, P mass in excess of the crop yield accumulates within the soil (Peukert et al., 2016, Bai et al., 2013, and Carpenter et al., 1998). Wetness index based fertilizer application strategies may reduce runoff at the expense of increasing soil P accumulation. Accumulated soil P could 1) limit the available soil capacity for fertilizer P from future applications, and 2) create the potential for large P runoff off events initiated by large infrequent precipitation events which generate runoff from a greater VSA extent.

Dairy manure, as applied, is typically rich in P relative to N:P plant growth requirements (ASAE, 1998); because N is easily lost through leaching and volatilization, the effective N:P ratio is enriched in P. It has been demonstrated that a fertilizer and soil nutrient imbalances may result in an accumulation of soil P (Pizzeghello et al., 2011, 2016) and exacerbate non-point source P pollution (Toth et al., 2005; Waldrip-Dail et al., 2009; Shafqat and Pierznski, 2010; Shafqat and Pierznski, 2013; Sharpley et al., 2013; Komiyama et al., 2014; Moshia et al., 2014). Komiyama et al. (2014) demonstrate that fertilizer applications based on P growth requirements