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Managing agricultural phosphorus for water quality: Lessons from the USA and China

Andrew Sharpley[1,*], *Xiaoyan Wang*[2]

[1]*Department of Crop, Soil and Environmental Sciences, Division of Agriculture, University of Arkansas, Fayetteville, AR, USA*
[2]*College of Resources, Environment & Tourism, Capital Normal University, Beijing 100048, China. E-mail :* cnuwxy@gmail.com

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ABSTRACT

The accelerated eutrophication of freshwaters and to a lesser extent some coastal waters is primarily driven by phosphorus (P) inputs. While efforts to identify and limit point source inputs of P to surface waters have seen some success, nonpoint sources remain difficult to identify, target, and remediate. As further improvements in wastewater treatment technologies becomes increasingly costly, attention has focused more on nonpoint source reduction, particularly the role of agriculture. This attention was heightened over the last 10 to 20 years by a number of highly visible cases of nutrient-related water quality degradation; including the Lake Taihu, Baltic Sea, Chesapeake Bay, and Gulf of Mexico. Thus, there has been a shift to targeted management of critical sources of P loss. In both the U.S. and China, there has been an intensification of agricultural production systems in certain areas concentrate large amounts of nutrients in excess of local crop and forage needs, which has increased the potential for P loss from these areas. To address this, innovative technologies are emerging that recycle water P back to land as fertilizer. For example, in the watershed of Lake Taihu, China one of the largest surface fresh waters for drinking water supply in China, local governments have encouraged innovation and various technical trials to harvest harmful algal blooms and use them for bio-gas, agricultural fertilizers, and biofuel production. In any country, however, the economics of remediation will remain a key limitation to substantial changes in agricultural production.

Introduction

Since the late 1960s, point sources of water quality impairment have been reduced due to their ease of identification and the passage of the Clean Water Act in the U.S. in 1972. However, water quality problems remain, and as further point-source control becomes less cost-effective, attention is being directed towards the role of agricultural nonpoint sources in water quality degradation. In a 1996, over half of surveyed waters in the U.S. were nutrient impaired (U.S. Environmental Protection Agency, 1996). Nearly 20 years on, continuing water quality impairment has led to major initiatives to reduce losses from the Chesapeake Bay Watershed (Kovzelove et al., 2010; U.S. Environmental Protection Agency, 2010a) and Mississippi River Basin (National Research Council, 2008).

Phosphorus (P) inputs to fresh waters can accelerate eutrophication (Carpenter et al., 1998). Although nitrogen (N) and carbon (C) are also essential to the growth of aquatic biota, most

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* *Corresponding author*. E-mail: sharpley@uark.edu (Andrew Sharpley).

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of the attention has focused on P because of the difficulty in controlling the exchange of N and C between the atmosphere and water, and fixation of atmospheric N by some blue-green algae (Schindler et al., 2008). Thus, control of P inputs is critical to reducing freshwater eutrophication. For water bodies with naturally higher salt content, as in estuaries, there are likely unique site specific critical concentrations of both N and P that generally limit aquatic productivity (Howarth et al., 2000).

Eutrophication has been identified as the main problem in surface waters having impaired water quality (U.S. Environmental Protection Agency, 2002). Eutrophication restricts water use for fisheries, recreation, industry, and drinking, due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition. Also, periodic blooms of cyanobacteria and other harmful algal blooms contribute to a wide range of water-related problems including summer fish kills, unpalatability of drinking water, and formation of trihalomethane during water chlorination in both the U.S. and China (Fig. 1). Clearly the incidences and severity of blooms has increased over the last 50 years.

In the last 20 years, efforts to reduce or control eutrophication and to lessen further impairment have transitioned from dealing with the effects of eutrophication to identifying and targeting the sources of nutrients in a watershed for treatment. As a result, targeted management strategy is now in place in most impaired waters of the U.S., as for example in the New York City drinking water supply watersheds, Chesapeake Bay Watershed, Florida, inland and coastal waters, Lake Erie Basin, and Mississippi River Basin (Sharpley et al., 2003; U.S. Department of Agriculture and Environmental Protection Agency, 1999). In fact, this is one of the main premises of the Total Maximum Daily Load (TMDL) approach to controlling impairment (U.S. Environmental Protection Agency, 2010b), where source apportionment, usually by watershed models, identify the sources and relative reductions needed to return waters to a desired eutrophic state.

Phosphorus and N are typically treated separately by scientists and environmental managers. The theoretical parsing of these elements may be partly attributed to the differing mobilities of P and N in soils; P is often insoluble and primarily transported in erosion and runoff, while N is highly soluble and readily leached. Even so, such a separation is artificial as P and N occur simultaneously in watersheds and farmers manage them together. Thus, as we move forward to remediate water quality, both N and P must be considered in concert.

1. Phosphorus flows in evolving agricultural production

In recent years, geopolitical and food security concerns have focused their attention on geologic P, causing some to predict a peak in P supply from global reserves (Sattari et al., 2012). The consequent responses in resource economics mean that new supplies of mineral P have been identified, mainly in Morocco (Jasinski, 2012; Rustad, 2012) and a peak in P supply in the near future is now considered unlikely (Scholz and Wellmer, 2013). In fact, China's agriculture has one of the highest fertilizer and pesticide application rates worldwide in order to support its large population (Fig. 2a). China is one of the largest producers and consumers of chemical fertilizers in the world, and the excessive nutrient loading from agricultural watersheds is considered to be the important source of nonpoint source pollution (Wang, 2006).

These flows of P in the U.S. and China are demonstrated in Fig. 2. Mineral phosphate consumption in China (Sun et al., 2012) has increased dramatically since the 1990s and continues to rise. At the same time there has also been a dramatic four-fold increase in livestock production in the country (Wang, 2005) (Fig. 2a). These trends tend to lag behind those of the U.S., where P fertilizer consumption has stabilized around 2005, due to new water quality guidelines

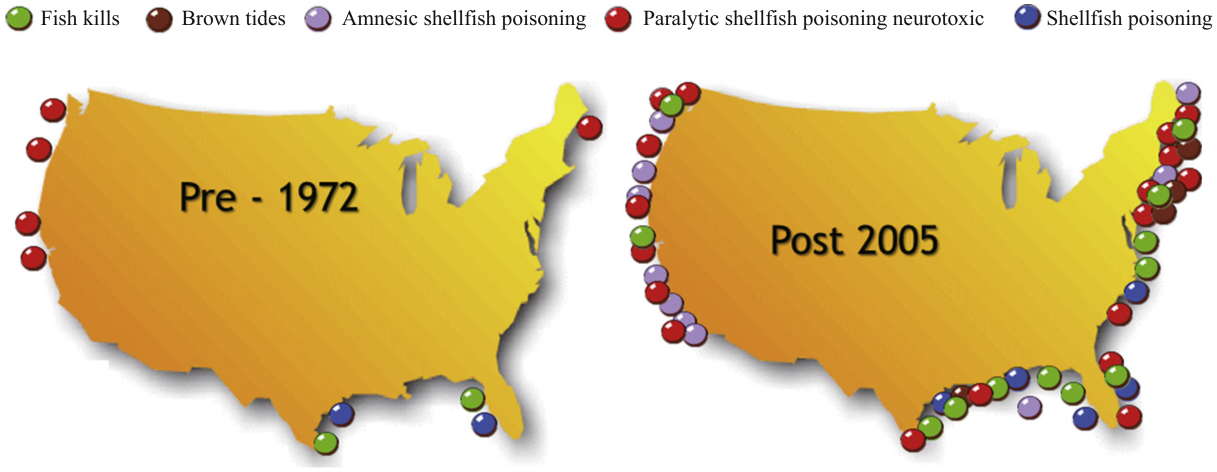

Fig. 1 – Extent of harmful algal blooms in U.S. coastal waters before 1972 and since 2005 (National Oceanic and Atmospheric Administration, 2013) and *Skeletonema costatum* in East China Sea for 2010 (Shen et al., 2012).