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AGRICULTURE AND EUTROPHICATION OF FRESHWATERS: A REVIEW OF CONTROL MEASURES

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ABSTRACT

Agriculture contributes a larger percentage of phosphorus (P) to freshwaters eutrophication. Fertilizers and manures applications over a period of time lead to P soil build up exceeding the required needs of the crops. Excess P is transferred into the waters through runoff, erosion, leaching and artificial drainage which impairs water quality, restricts water use for fisheries, promotes harmful algal bloom of Cyanobacteria and Pfiesteria - which pose serious health hazards to livestock and humans. Many measures are taken toward the control of P loss from agricultural soil into the water. Tremendous reductions were achieved in the P loss concentrations from soil to water. However, these control measures could only help in reducing the concentration of particulate phosphorus (PP) which is associated with soil particles. Dissolved phosphorus (DP) still finds its way into the waters. Further efforts must be made toward reducing the P loss from agricultural soil into waters to the minimum levels.

Keywords: Eutrophication, Phosphorus, Freshwater, Agriculture

INTRODUCTION

Phosphorus (P) is an essential nutrient for the growth of both animal and plant, and its input is recognized as necessary in maintaining profitable crops and livestock production and in meeting food requirements globally (Daniels *et. al.*, 1998; Sharpley and Tunney, 2000, Sharpley *et. al.*, 2000). However, P can become an environmental concern by accelerating eutrophication of freshwaters (Sharpley *et. al.*, 2000; McDowell *et. al.*, 2002,).

Eutrophication is a natural process whereby freshwater bodies receive excess nutrients especially P which stimulates algal growth and deoxygenation of rivers caused by the death and decomposition of undesirable algae.

In addition, many surface waters could over the time experience periodic and massive harmful algal blooms of *Cyanobacteria* and *Pfiesteria* which caused a large amount of water problems including fish kills and formation of *trihalomethane* during water chlorination (Daniel *et. al.*, 1998, Bundy *et. al.*, 2001). Water soluble neuro and hepatoxins are released following the death of algal blooms and when consumed can kill livestock and may be a serious health hazard to human. The natural environment recreational value and aesthetic is highly degraded by eutrophication and both local and regional economies could be seriously affected (Daniel *et. al.*, 1998). The U.S. Environmental Protection Agency (USEPA) and European Environment Agency (EEA) have identified eutrophication as a major cause of impaired water quality (Sharpley *et. al.*, 2000). And in 1972, Clean Water Act was passed in the USA, and since then a lot of positive impact has been made in controlling point sources of pollution of freshwaters (Sharpley *et. al.,* 1994). Point sources of P inputs into surface waters from discrete defined sources which are sewages and industrial discharges have reduced tremendously. These were achieved by pollution control standards, regulatory enforcement, capital investment and a good management in industrial and municipal infrastructures (Daniel *et. al.,* 1998, Weld *et. al.,* 2002). However, less attention has been directed in controlling nonpoint sources of P, this is largely due to the difficulty involved in their identification and control. Controlling nonpoint sources of P remain a hindrance in the protection of surface waters against eutrophication (Sharpley *et. al.,* 1994, Weld *et. al.,* 2002).

The Role Of Agriculture

Nonpoint sources originate from both agriculture and urban areas, however agriculture is a major contributor than urban areas (Weld *et. al.,* 2002). Agricultural nonpoint sources of P are the major sources of nutrients in 50% of lakes and 60% of rivers that are identified to have impaired water quality in the U.S.A. (Daniel *et. al.,* 1998, Gburek and Sharpley 1998).

The increasing incidence of eutrophication both in the UK and globally has shown the contribution of nonpoint sources of P from agricultural land (Sharpley *et. al.,* 2000, Neil *et. al.,* 2001). According to Neil *et. al.,* (2001) the number of rivers, canals and lakes designated as sensitive to eutrophication by the Environmental Agencies in England and Wales increased from 33 in 1994 to 61 in 1998. Uusi-Kamppa *et. al.,* (2000) also reported that the contribution of agricultural P to surface waters in the Nordic countries as 15, 20, 17 and 41% of the total P loading in Denmark, Norway, Sweden and Finland respectively.

Over many decades, the P loss from agriculture to watercourses has increased as a result of the development of more industry-based types of agriculture and increased intensive farming. In some places, more P is added to agricultural systems than transferred in crop or animal products especially in areas of concentrated intensive livestock operations where manures and other agricultural residues are being applied to the land, and most times the soil P levels are increased beyond the required needs (Gburek *et. al.,* 2000, Simard *et. al.,* 2000). When the saturation degree of soil P sorption capacity increases, some of this P could be transferred to surface waters (Sims *et. al.,* 2000). This P transfer, even at the very low concentrations may cause eutrophication in surface waters. P is transferred into surface waters either by overland flow (erosion and runoff) and subsurface flow (leaching) which occurs naturally in undisturbed soils, but could also be enhanced by artificial drainage systems (Simard *et. al.,* 2000). P exists in water as dissolved P (DP), which is readily available for algal uptake, and particulate P (PP) which is associated with soil particles and eroded materials, and is a long-term P source in water. Frossard *et. al.,* (2000) reported that the intensive agricultural production has increased P losses from soils through increased runoff, erosion and leaching which in turn have adverse effects on water quality. When water quality is impaired, remedial strategies can be so difficult and quite expensive in implementing, and could take many years before water quality improvements are realized (Sharpley *et. al.,* 1994; Gburek *et. al.,* 2002).

Fertilizer Utilization

McDowell *et. al.,* (2001) reported that the trend of increased usage of fertilizers in crop production over the last fifty years has fragmented farming systems and the specialized crop and livestock operations efficiency coexist in different regions within and among countries have led to P surplus inputs in feed and fertilizer in these areas compared to outputs.

According to Sharpley *et. al.,* (1998) the rapid growth and intensification of livestock industry in certain regions in the USA and Europe have created imbalances between P input in feed and fertilizer and its output in produce. On a national basis, an annual P surplus of $26kgha^{-1}$ exists in the USA, while surplus for the UK is around $10kgha^{-1}$ (Sharpley and Withers 1994).

Higgs *et. al.,* (2000) cited that 30-50% of the increased in world food production since the 1950's is attributable to fertilizer use, including P use. Data from the International Fertilizer Association (IFA, 1997) showed that in 1984, phosphate fertilizer use (expressed in terms of P_2O_5) in the developed countries was 9.7Tg, almost twice that of developing countries at 5.3Tg. By 1995, the developing countries had increased to 8.3Tg and were around 5% more than that of developed countries, and this was in recognition of the need to raise the P status of their soils.

The long-term use of fertilizers in areas of intensive agricultural production has increased P in many soils to optimum or excessive levels (Gburek and Sharpley, 1998; Sharpley *et. al.,* 2000). This condition results in increased P loss in runoff from the land and contributes to the eutrophication of freshwaters as noted by Sharpley *et. al.,* (1994). The lands of intensive row crops production may also receive excess P because of low efficiency of some P fertilizers and this result in P accumulation in near surface and subsoil (Simard *et. al.,* 1995).

Manure Usage

Animal waste is a leading source of P pollution from agricultural sources. It is applied to farmlands as organic source of plant nutrients and organic matter for the physical and fertility improvements of the soils (Ertl *et.al.,* 1998; Dao and Carigeth, 2003). P from animal manure is associated with significant degradation of surface water (He and Honeycutt, 2001). And this is more of increasing concern in the USA, especially in areas of concentrated animal productions (Sharpley *et.al,* 1994; McDowell and Sharpley, 2003). In addition, swine and poultry waste account for about 18% of total animal waste in the USA (Ertl *et.al.,* 1998). Huge amounts of dairy manure are produced in Wisconsin, California, Florida and Texas, swine manure in Iowa and Indiana, and poultry manure in Alabama, Delaware, Georgia, North Carolina and Oklahoma (Sharpley *et.al.,* 1994). Most manure is bulky due to the liquid volume or incorporated bedding materials. Thus, manures have a lower nutrient content than mineral fertilizers, and much more than commercial fertilizer must be applied to achieve similar nutrient additions. Some crop production systems are forced to continually use manures as fertilizers because of the lack of viable alternatives for manure disposal. These systems always build soil P levels well beyond the acceptable optimum ranges for agronomic crops, because they are applied at rates to meet crop N requirements without credits being given to P needs (Sharpley *et. al.,* 1996). In areas of intense animal production, local agricultural land always becomes a disposal site for large quantities of animal waste. And this result is an accumulation of P in the soil runoff and leaching of excessive P in the soils can result in the eutrophication of surface waters (Robinson and Sharpley, 1995; Ertl *et.al.,* 1998).

The Control Measures

Sharpley *et. al.,* (2000) cited that there is a need to develop agricultural systems based on meeting minimum P requirements for crop and livestock production, i.e., maximum P-use efficiency with minimal adverse effects on surface waters. Hence, some practices which serve as control measures are adopted in order to prevent soil P build up, and also minimize P loss in runoff to water bodies. They are referred to as BMPs. According to Moore *et. al.,* (1995), the concept of BMPs (Best Management Practices) was introduced in Public Law 92-500 which outlined several rigorous requirements for a practice to qualify as a BMP. The practice must relate directly to water quality and be cost effective. Since the late 1970s, several studies have investigated the long-term (7-10 year) effectiveness of BMPs to reduce P export from agricultural watersheds (Sharpley and Rekolainen, 1997). These studies quantified P loss prior to and after BMPs implementation or attempted to use untreated watersheds as controls. Overall, these studies showed BMPs reduced P export. For example, water quality improvements have been demonstrated after the BMPs implementation in several parts of the world (Bottcher *et. al.,* 1995;

Gillingham and Thorrold, 2000, Uusi-Kamppa *et. al.,* 2000). BMPs are available for the protection and maintaining water quality, and some of them were initially used for erosion control, while many are new and specifically designed for protecting water quality (Moore *et. al.,* 1995). Generally, BMPs could be classified as: structure and source controls and land management practices.

Structure and Source Controls

Practices that fall under this classification are those that help in limiting P transport through water management. They include buffer strips, grass waterways, sediment catch basins, wetlands, cover crops, terrace, manure storage facilities etc. They are quite effective, and easy to manage, and help in controlling P loss at the source rather than after entry into aquatic system.

Land Management

The practices manipulate the soil system to minimize soil P loss to surface water or groundwater. They include timing and placement of manure, nutrient management, irrigation scheduling of liquid manure to limit groundwater contamination, application method (broadcast versus incorporation) (Moore *et. al*., 1995; Uusi-Kamppa *et. al*., 2000).

Cover Crops

The presence of cover crops would reduce the risk of surface runoff and erosion, and this may be quite beneficial for total phosphorus (TP) control, but subsurface losses DP may be enhanced. Unger *et.al.,* (1998) showed that cover crops reduced surface runoff by up to 50% due to increased infiltration. Similar reduction of total nitrogen (80%) and TP (71%) were also recorded due to vegetative protection, but the impact on DP (37% reduction) was less pronounced.

Similarly, Yli-Halla *et. al.,* (1995) reported that erosion control measures designed to reduce TP loads do not necessarily reduce eutrophication, because DP losses through leaching may remain high. The cover crops and residues are more efficient at reducing PP than DP losses. These approaches in controlling P export could only work where subsurface pathways of P losses are unimportant. These controls are effective in surface runoff generating areas but quite ineffective in recharge areas.

Buffer Zones and Wetlands

Buffer zones (i.e. uncultivated areas between fields and water courses), constructed wetlands, and ponds have been established to slow down runoff water from agriculture, enhance infiltration, and sorbs P to soil and vegetation within the buffers, thereby trapping sediments and nutrients (Uusi-Kamppa *et. al.,* 2000). The effectiveness of buffer strips in the removal of large proportion of P from runoff may also decline with time. Cooper *et. al.,* (1995) noted that a riparian pasture that had been set aside for 12 years acted as a source rather than a sink of dissolved reactive phosphorus (DRP) to receiving waters. Studies that were conducted by others have also demonstrated that buffer strips may act as a source of DRP while still acting as a sink for TP (McDowell *et. al.*, 2004). The results of research conducted in the Nordic area of Europe shown that buffer zones effectively diminish TP in runoff from agricultural land in long-term and short-term experiments as the retention of TP varied from 27 to 97% (Uusi-Kamppa *et. al.,* 2000). Also, P removal by wetlands generally decline after a period of years or decades depending on loading rates, hydraulic retention time, wastewater characteristics, wetland subtraction and areas (Reddy *et. al.,* 1995; Fennessy and Crank 1997). Hylander and Siman (2001) reported that in addition to natural wetlands, constructed wetlands can be built with soil, gravel, zeolite, limestone and slag. But a major problem associated with constructed wetlands that treat highly organic wastewaters (e.g. dairy wastewaters) is the clogging of the pore space by accumulated refractory [humic acid, fulvic acid and human] organic solids (Nguyen 2000).

Phosphorus Index

Phosphorus Index (PI) is a field-oriented matrix system that integrates soil P availability, fertilizer and manure, waste management and transport processes (erosion and runoff) to rank sites within a given watershed, in terms of their potential to deliver excess P to surface waters (Sharpley *et. al.*, 1994). It is a field tool used in identifying soil vulnerability to P runoff. PI values are also grouped into site vulnerability categories in guiding BMPs application to the site (Gburek *et. al.*, 2000) and to simulate the effects of changing soil and crop managements and land uses on nonpoint source pollution of surface waters (Sims *et. al.*, 1998).

In the USA, the use of PI is promoted on state by state basis, and in New Zealand, PI is being used commercially as part of a nutrient management package for farmers. Further research is needed on PI for continued refinement and improvement so that it can become an effective tool for integration in planning programme for nutrient management (Gburek *et. al.*, 2000).

Nutrient Management Plans and Acts

Nutrient Management Plan (NMP) is a simple plan for the farmers that provide recommendations on the quantities of manure and fertilizer to apply to each field (Beegle *et. al.,* 2000). The actual plans themselves will take on many plans. NMP is critical for maximizing the economic benefits from nutrients while minimizing the environmental impact. Beegle *et. al.*, (2000) reported that in Northern Ireland, the acceptance of nutrient-management scheme was excellent, with more than 90% of farmers taking part voluntarily, and this indicating the benefits of NMP to farmers and society. VanDyke *et. al.*, (1999) also cited a case study analysis estimates of a field-level and farm level nutrient loss reductions and associated income impact of nutrient management practices on 4 Virginia livestock farms. After the farms adopted a NMP, average annual N losses decreased by 23 to 45%, P losses decreased on 3 farms by23 to 66% and net income increased by \$395 to \$4,593. A survey of farmers in the Erne Catchment Nutrient Management Scheme (ECNMS) in 1996 indicated that 75% of the farmers implemented their NMP and saved an average of £22ha-1yr^{-1} on fertilizer purchases according Beegle *et. al.*, (2000). In view of the importance of NMP in order to address farm nonpoint source or field nutrient losses, some acts were enacted in order to give NMP legal backing, examples are: Maryland Water Quality Act of 1998, Delaware Nutrient Management Act 1999, Virginia Poultry Management Bill of 1999, (Penn and Sims 2002), Irish Waste Management Act, Pennsylvania Nutrient-Management Legislation 1993, and Erne Catchment Nutrient Management Scheme (ECNMS) of 1996. (Beegle *et. al.*, 2000).

Other Control Measures

In order to restrict soil P loss into a lake Calhoun *et. al.*, (2002) cited a recent evidence that decreasing fertilizer sales and more efficient soil management over the past 20 years has decreased P losses into the north-western Ohio River, which drains into Lake Erie.

Also, manure and soil treatment and amendment to decrease P solubility and potential release to overland flow, feeding animals the actual P needed, use of soil testing to guide future P application, and efficient redistribution of manure within and among farms will also reduce soil P losses. Further decreases can be achieved by identifying Critical Sources Areas (CSAs) and targeting conservation measures such as adding high P sorbing materials like coal combustion by-products (Stout *et. al.,* 2000). Djodjic *et. al.*, (2002) also reported that cultivation immediately after application can decrease P losses if erosion is minimized. Periodic tillage of the soil can decrease P loss by the redistribution of high-P topsoil throughout the root zone and the disruption of subsurface P loss pathways (macropores).

CONCLUSION

Several studies have indicated decrease in lake productivity with reduced P inputs following implementation of conservation measures. These measures help in reducing PP mainly, while DP still finds its way into the water bodies, hence eutrophication occurs after a period of time. Further research needs to be done on all the control measures in order to curtail soil P from agricultural land into surface water, at least to the minimum level. All efforts are towards decreasing the P loss into freshwaters and it seems quite impossible not to have agricultural P loss transported into surface water presently.

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