Phosphorus Balance Trends on Agricultural Soils of the Lake Erie Drainage Basin

By Laura Bast, Robert Mullen, Ivan O'Halloran, Darryl Warncke, and Tom Bruulsema

Only a few decades ago, optimum plant nutrition involved applying more P than crops removed. In recent years, applications have come much closer to balancing removals. This trend has positive implications for both crop productivity and water quality.

Agriculture is one of the sources of P that feeds into Lake Erie. Reductions in total P loading since the 1960s have improved water quality in the lake, but in the past 10 years a rebound in loading of dissolved reactive P has raised new concerns (Baker, 2008).

The purpose of this article is to examine the trends in the balance of the major inputs and outputs of P on the agricultural soils of Ontario, Michigan, and Ohio. Much of the lake's watershed is within these three jurisdictions. While significant agricultural areas within each also drain elsewhere, accurate data representing agricultural activities is easier to obtain for political rather than watershed boundaries. In addition, since agricultural trends are driven by many external factors (markets, technology, etc.) it is not likely they would differ greatly among watersheds. Just under half of Ohio's and about 40% of Ontario's cropland drains into Lake Erie. Approximately 67% of the Lake Erie drainage basin is in agricultural land use (USEPA, 1995).

Agricultural producers apply P inputs to soils in the form of fertilizer and manure to support optimum growth of crops, and to replace the P removed with harvest. The balance between the amounts applied and removed determine whether soils are being built up or depleted in P. Enrichment of soils in P is one of several factors influencing loss of P to surface waters. Other factors include tillage and crop residue management through their influence on surface runoff and soil erosion.

The balance between amounts applied and removed serves as a performance indicator for P management. Attaining a proper nutrient balance while producing optimum crop yields can only be done by adopting best management practices (BMPs) for soils, crops, and nutrients.

Manure Inputs

Producers with livestock generally apply manures to their soils to capture the value of the nutrients they contain. However, not all manure is recovered, since not all animals are raised in confinement, and some manure (although a relatively minor amount) is lost in storage and handling. While total soil P includes all of the manure P applied to and remaining in the soil, manures vary in the degree of availability of the P they contain, and thus their immediate and long-term impact on soil test P levels and plant-available P may differ.

We estimated the total amount of manure P, "as excreted," and "as applied" to land, by applying coefficients from Kellogg et al. (2000) to inventory statistics for cattle, swine, and poultry from Statistics Canada and USDA-NASS. The figures for "as excreted" include all the P in all manure excreted, while those for "as applied" include only the plant-available P fraction in the recoverable manure. These coefficients result in amounts of P "as applied" similar to those calculated using values for manure nutrient content found in extension publications (e.g., OSU, 2006) based on animal type and size.

Over time, livestock have become more productive, partly by increasing feed conversion efficiency, and partly by increasing the output of meat, milk, and eggs per head. Some animals are now raised to higher weights than in the past; others are raised to market weight more quickly (e.g. more cycles per year for broilers). Feed conversion efficiency improvements lead to less manure excretion per unit of production, but other sources of productivity improvement increase manure excretion per unit of inventory.

Ohio, Michigan, and Ontario have the largest agricultural areas in the Lake Erie drainage basin, which is part of the larger Great Lakes watershed. Source: U.S. Army Corps of Engineers, Detroit District.

Abbreviations and notes for this article: P = phosphorus; tonnes = metric tons.

The coefficients in Kellogg et al. (2000) are based on animal performance in 1998. Comparing inventories and production statistics over the past 10 to 20 years, it is apparent that the livestock industry has been improving per-head productivity by roughly 10% each decade. Assuming that half of this productivity increase arose from improved feed conversion efficiency, we incremented the manure excretion coefficients by 0.5% of the 1998 value for each year after 1998, and likewise decreased the coefficients by the same amount for each year prior to 1998.

This productivity adjustment results in a linear 26% increase in the coefficients from 1955 to 2007. It can be argued that the amount of the adjustment should be higher or lower, but this adjustment is likely to be more accurate than assuming no change in manure output per unit of inventory over the period. Even though we assume an increase in the amount of manure excreted per unit of inventory, the total amount of manure available to spread on land has essentially remained the same–increasing by only 6%–over the past 50 years.

Cattle numbers were stable from 1955 to the mid-1970s, but have declined steadily since then. The number of swine followed the trend of cattle in Ohio, but in Michigan and Ontario swine numbers increased from the mid-1970s to the mid-1980s. In Ontario, numbers increased again in the last 10 years. Poultry populations increased sharply 20 years ago in Ohio and 10 years ago in Michigan, but in Ontario they have been increasing slowly and steadily since 1965.

Fertilizer Inputs

The publication Commercial Fertilizers (Terry, 2006) supplied sales data on an annual basis going back to 1975, and in 5-year intervals as far back as 1955, for Ohio and Michigan. Fertilizer sales in Ontario were reported by The Fertilizer Institute of Ontario for the period 1955 to 1965, by Agriculture Canada from 1966 through 2002, by the Canadian Fertilizer Institute from 2003 through 2006, and most recently by Statistics Canada for 2007.

We included fertilizer for non-farm uses, since data were not available for consistent estimates of the proportion used for non-farm purposes, including home lawns and gardens, recreational fields, golf courses, etc. Estimates of the proportion of fertilizer P used for non-farm purposes range from a few percent in Ohio (USGS) to 10% in Michigan in 1996 (USEPA).

Use of fertilizer P increased steadily from 1955 to about 1980, but decreased rapidly in the 1980s and has remained relatively stable since then. Prices for P fertilizer spiked upward in 2008. Crop prices also increased sharply, but not enough to prevent the price ratio for P relative to crops from attaining the highest levels seen in the past 30 years.

Crop Removal Outputs

We estimated the removal of nutrients harvested using crop production statistics from USDA-NASS and Statistics Canada for hay, corn, oats, barley, wheat, rye, soybeans, dry beans, and potatoes. The total area of these crops has changed little since 1955, though the soybean area has increased at the expense of hay and some of the cereals. These crops accounted for about 95%, 93%, and 99% of the total cropland in Ontario, Michigan, and Ohio, respectively, in the most recent agricultural census. We assumed that the crops on the remaining area removed P at the average rate of the listed crops.

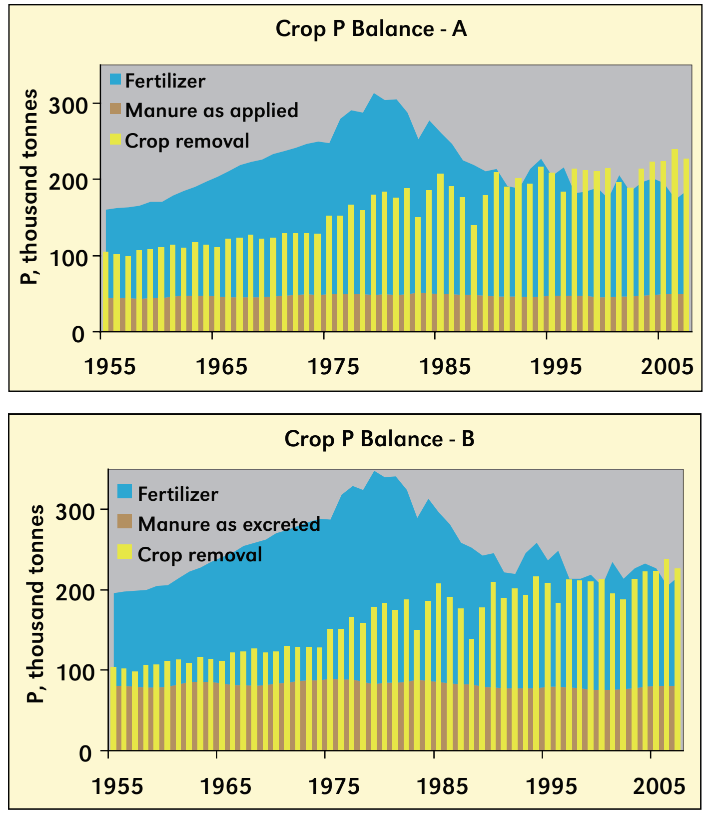

Figure 1. Crop P balance for Michigan, Ohio, and Ontario, based on manure P as applied (A) and as excreted (B).

We used coefficients for P content of the harvested crops from extension publications (OSU, 2006; OMAFRA, 2006) as much as possible, using IPNI (2001) coefficients for crops with no regional data.

Trends

We show the sum of fertilizer and manure inputs as a stacked area chart in **Figure 1**, with crop removal superimposed as a bar chart. The amounts represent the total cropland area of Ontario, Michigan, and Ohio. Units are metric tons (tonnes) of the element P. To convert these figures to P_2O_5, the standard unit of measure for fertilizer, multiply by 2.29.

Owing mostly to increases in crop yields, crop P removal has more than doubled since 1955. Year-to-year variations in weather cause considerable fluctuation in the amount removed, even when averaged across this rather large geographical area. Continued price increases for crops, crop breeding efforts, and refinement of best management practices are likely to spawn continued growth in crop P removal.

Current crops remove on average about 220 thousand tonnes of P. Relative to the loading levels estimated for Lake Erie from its drainage basin, this is a large quantity. Crop producers balance the removal by applying fertilizer and manure in order to maintain the productivity of crops. The large quantity underscores the importance and high sensitivity of managing nutrients appropriately to prevent avoidable losses impacting water quality.

The balance between inputs and removals changes considerably depending on whether manure P inputs are estimated as applied or as excreted. Compare **Figure 1A** with **1B**. With manure P as applied, there was a deficit for 9 of the past 11 years. On the as-excreted basis, there was a deficit for only

Balancing between the extremes of excess algae in drainage water and crop P deficiency requires careful attention to BMPs.

2 of the past 11 years. Estimated either way, P inputs greatly surpassed removals prior to 1990. Since P is strongly retained in soils, much of the surplus P has likely contributed to a buildup in soil P fertility. The improved P fertility has benefited crops. When soils are low in P, recommended rates of application often exceed the removal rate. At somewhat higher soil test levels, applications that do not exceed crop removal suffice for optimum crop yields, while soils with even higher soil test P levels can produce optimum crop yields with little or no P inputs.

The proportion of soils on which crops were limited by P availability in 2005 was estimated at 28, 30, and 42% for Ontario, Michigan, and Ohio, respectively (PPI, 2006). Comparison to historical soil test levels is confounded by changes in sampling distributions, but there has likely been a decreasing trend in this proportion over the past 50 years. Rising levels of soil test P would be consistent with expectations based on the historical P surplus. Considering that inputs and removals have recently become more closely balanced, it is unlikely that soil P fertility in general will continue to increase. Further increase in the P balance deficit could raise the risk of P deficiencies limiting crop yields.

The estimated fraction of manure P applied has increased over time. Comparing **Figure 1A** with **1B**, the as-applied fraction increased from 55% in 1955 to 61% in 2007, mostly owing to fewer cattle and more poultry, since the proportion of manure collected and land-applied is greater for poultry than for cattle. Much of the fraction not applied to land is directly deposited on pastures. The fate of the remainder is important to the issue of water quality, but is beyond the scope of this article. The accuracy of the estimates of the applied fraction can be questioned, since the past decade or two has seen considerable change in nutrient management on livestock farms.

We have ignored land application of sewage biosolids, owing to lack of historical data. Calculating from figures in Schroder et al. (2008), we estimate that the total amount of biosolids P applied in 2002 amounts to less than 5% of crop removal for this region.

The agricultural P balance trend is a useful performance indicator for crop management practices, since it reflects changes in crop productivity as well as surplus P potentially liable to contaminate water. On the other hand, the P balance does not indicate uniformity of distribution. It is possible that soil P levels in some areas have increased to the point of elevated risk of water contamination, while in other areas soils receive suboptimal amounts of P. Nutrient management plans encourage the use of best management practices (BMPs) to ensure that manure nutrients are directed to soils with lower nutrient levels and with lower risk of P loss to surface waters. Surveys of soil test P are a useful complement to the nutrient balance indicator.

Ms. Bast is a M.Sc. candidate at Ohio State University. Dr. Mullen (e-mail: mullen.91@osu.edu) is Extension Soil Fertility Specialist, Ohio State University. Dr. O'Halloran is Associate Professor, Ridgetown Campus, University of Guelph. Dr. Warncke is Professor, Michigan State University. Dr. Bruulsema is IPNI Northeast Region Director, located at Guelph, Ontario.

References

Baker, D. 2008. Presented to the Ohio Phosphorus Task Force. Available online at: http://www.epa.state.oh.us/dsw/lakeerie/ptaskforce/BakerBullets.pdf (confirmed 2 October 2008).

Kellogg, R.L., C.H. Lander, D.C. Moffitt, and N. Gollehon. 2000. USDA-NRCS-ERS Publication No. nps00-0579.

IPNI. 2001. Nutrients Removed in Harvested Portion of Crop. http://www.ipni.net/nutrientremoval.

OSU. 2006. Ohio State University Bulletin 604 – Ohio Livestock Manure Management Guide. http://ohioline.osu.edu/b604/

PPI. 2006. The Fertility of North American Soils.

Schroder, J.L., H. Zhang, D. Zhou, N. Basta, W.R. Raun, M.E. Payton, and A. Zazulak. 2008. Soil Sci Soc Am J 72: 73-82.

Terry, D.L. 2006. Fertilizer Tonnage Reporting in the U.S.—Basis and Current Need. Better Crops 90(4):15-17.

USEPA. 1995. The Great Lakes: An Environmental Atlas and Resource Book. http://www.epa.gov/glnpo/atlas/gl-fact2.html