VERTICAL REDISTRIBUTION OF MANURE P AND FERTILIZER P IN LONG-TERM FERTILITY TRIALS AT ARLINGTON, WISCONSIN: MINING NEW PHOSPHORUS DATA FROM OLD PLOTS

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Abstract

Knowledge of the fate of agricultural phosphorus in the environment is of crucial interest for maintaining water quality and sustaining economic agricultural enterprises on the landscape, in Wisconsin as well as elsewhere. Since the question is most properly the long term effect of a particular phosphorus-management practice, the only alternative to pure forecasting or prediction is the challenge of extracting pertinent information from long-term experiments that were established for purposes other than evaluating the fate of phosphorus in the environment.

A set of fertility plots established in 1962 at the UW Agricultural Research Station at Arlington, WI, included addition of dairy manure at a rate of 15 ton/acre/yr for 32 years and addition of phosphorus fertilizer for 20 years. Since the cessation of treatment applications in 1994, the plots-have been only minimally disturbed. In a preliminary study, the plots and treatments were re-marked and a number of soil cores to a depth of 1 m representing treatments of immediate interest. Measures HF-extractable P show clear differences in the 20-cm plow layer between those cores amended with mineral P fertilizers and with P-containing dairy manure, presumably reflecting P loading rates. However, the pattern of P distribution with depth below the plow layer is even more striking, with manured soil behaving like a chromatographic column, with available-P enriched as much as 20-cm below the plow layer, whereas the mineral-P treatment affects a depth of only 5 cm below the plow layer. Further work is underway to revisit these long-term plots in a scientifically rigorous manner and “mine” information about the long-term fate of phosphorus in a Wisconsin soil from this long-term experiment.

Introduction

Knowledge of the fate of agricultural phosphorus in the environment is of crucial interest for maintaining water quality and sustaining economic agricultural enterprises on the landscape, in Wisconsin as well as elsewhere. With increased awareness of environmental issues associated with phosphorus in surface waters, the trend is toward increasing regulation of phosphorus efflux from households (e.g., as detergents), from cities (as discharged effluents), and from farms as runoff and subsurface leachates. While the best intentions are
to make science-driven regulations, the overriding interest in taking decisive steps toward remediation of environmental contamination will often demand that policies such as

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Wisconsin’s NRCS 590 Standard will, at best, reflect on the best science currently available. Necessarily, new policies and regulations will rest on existing, and often old, methodologies and experimental designs. Since the question is most properly the long-term effect of a particular phosphorus management practice, the only alternative to forecasting or pure prediction is the challenge of extracting pertinent information from long-term experiments that were established for purposes other than evaluating the fate of phosphorus in the environment.

Materials and Methods

A long-term fertility experiment was laid out in 1962 by Prof. (Emeritus) Lloyd A. Peterson (Dept. of Horticulture and Soil Science, UW-Madison) at the Arlington Agricultural Research Station on soil classified as Plano silt loam, a fine, silty, mixed, mesic Typic Argiudolls. The fertility experiment was divided into two—“organic” plots and “mineral” plots. The organic plots received annual addition of composted dairy manure (15 tons/A), cut alfalfa hay (2 tons/A/yr), straw (2 tons/A/yr), rye, or no organic amendment (=control) for 30 years with triplicate 24x40 ft plots. The mineral plots were established with four levels of N (0 to 150 lb/A/yr as urea or ammonium nitrate) as the main treatment, four levels of K (0 to 240 lb/A/yr as potassium chloride or sulfate) as subplots, and four levels of P (0 to 120 lb/A/yr as monocalcium phosphate [”triple superphosphate”]) as subsubplots, all in a split-strip factorial arrangement with duplicate plots for each of the 4x4x4 treatments. On the mineral plots, P and K were added until 1982 (20 yr), at which time P and K application ceased. Since their inception, these fertility plots have been planted to a variety of horticultural crops common to Wisconsin agriculture and to corn from 1987-1993. In 1994, after 32 yr, addition of N fertilizer in the mineral plots and organic amendments organic plots ceased; plots have been planted but otherwise only minimally disturbed. These plots are credibly-laid out, replicated, and controlled experiments and have previously been the subject of peer-reviewed publications: Peterson and Krueger (1980), Liu et al. (1997), and Barak et al. (1997).

In March 2000, with the assistance of Prof. Peterson, plots on the Peterson organic and minerals trials were re-marked and a number of soil cores, 1 3/4 inches (39 mm) in diameter and 1 m deep, were taken (in triplicate, along the center line of each plot) with the soil probe truck operated by the Dept. of Soil Science, UW-Madison. Cores were returned to the lab in their capped plastic sleeves and, when necessary, stored at $4^{o}C$ until sectioning and analysis. Cores were opened by splitting the plastic sleeves in half lengthwise with scalpel blades assembled in a jig and then sectioned to 1- or 5-cm increments.

The sections were then split (in some cases, after segregating the topsoil infilling of earthworm channels), with one portion dried and homogenized and the other portion used for soil solution extraction. Soil water extraction used a heavy, immiscible liquid displacement technique that does not add water or salts during the process of extraction. The displacing liquid used was a hydrofluoroether that was first found suitable for this purpose

in this lab (Levine, 2000). Soil solution composition is determined by ICP-AES (50 ppb P detection limit) at the Soil and Plant Analysis Lab, Madison, WI.

On the dried subsamples in the preliminary tests, a number of standard phosphorus tests have been run: dilute acid-extractable P (“Bray I”) and total P by oxidation (H_2O_2) and digestion (HF). Extractable P is determined in-house using a modification of the classical ascorbic acid technique of Murphy and Riley (1962), miniaturized to sample 100 mg soil or 100 μL of extract in 96-well microplates and to be read in 15 sec and reported in spreadsheet format by a microplate reader. The microplate method also permits easy use of the method of standard additions for measuring total P after acid digestion, which introduces a complex matrix. In further work, additional measures of phosphorus pools will be evaluated, among them organic P by the ignition method (Kuo, 1996) and oxalate-extractable Fe and Al (a proposed measure of the sorptive capacity of soil for inorganic P, according to Schoumans and Groenendijk, 2000)

Results and Discussion

Preliminary results indicate that relative standard deviations (RSD) for the microplate spectrophotometric technique used in our lab averaged -3.5% or lower. Pending fuller statistical examination of results, reference will be made to several cores selected to be representative of the larger group sampled and analyzed. Dilute hydrofluoric acid extracts, traditionally used to evaluate P availability to plants (Bray and Kurtz, 1945), show clear differences in the 20-cm plow layer (in which mechanical mixing occurred annually) between those cores amended with mineral P fertilizers and with P-containing dairy manure, presumably reflecting P loading rates (Fig. 1). However, the pattern of P distribution with depth *below* the plow layer is even more striking, with manured soil behaving like a chromatographic column showing phytoavailable-P enriched as much as 20-cm below the plow layer, whereas the mineral-P treatment affects a depth of only 5 cm below the plow layer. (Additional information was gathered for a cm-by-cm evaluation of total soil P by digestion with HF and displacement of soil solution with hydrofluoroether, a heavy, immiscible liquid akin to a liquid Teflon, but data are not yet available.)

Results of this information mining of the long-term plots at Arlington will, in their simplest form, be a scientifically-credible point observation regarding the downward mobility of added phosphorus, both mineral P at three different levels and manure P; this information is directly relevant to subsoil leaching in areas of high groundwater or nearby surface water, particularly in the Wisconsin setting in which manure loading of agricultural land is as much an issue of animal husbandry as soil fertility management.

A second level of sophistication in data analysis will involve combining the older values of Bray P in the top 20-cm layer, published by Peterson and Krueger (1980) and collected until 1994 (but unpublished), with new numbers from the proposed 2001/2002 sampling. After calculating for estimated crop removal, the rate of "aging" of acid-extractable P into nonextractable forms can be calculated for a 20-yr period of no mineral P additions, starting from P levels that were built up over 20 years to different levels by the three different P fertilizer rates. This information regarding the long-term fate of available P under controlled conditions will provide valuable information about possible increased P capacity due to fixation.

A third level of sophistication in data interpretation is to test the applicability of the P sorption isotherm proposed by Schoumans and Groenendijk (2000) as the basis of their P level and leaching model:

$$Q = K\,c\,Q. / (1 + K\,c)$$

where Q is the amount of adsorbed P, K is an empirically-derived adsorption constant, c is the ortho-P concentration in soil solution, and $Q.$ is the sorption capacity of a soil for P, roughly equal to 1/6th the amount of oxalate-extractable Fe and Al (i.e., poorly-crystallized Fe and Al oxide content, in mole units). The individual increments of soil have a large range of available-P levels so that this equation may be parameterized using field soils instead of lab soils to which fresh additions of P have been made. Success in parameterizing this equation means that existing soil phosphorus models, such as that of Schoumans and Groenendijk (2000), that-though simple-could be used to model soil P test values and annual leaching rates using the best science currently available.

An obvious uncertainty in this experiment is exactly how much P was applied as manure to the manured soils. Current nutrient analyses for the same experimental farm will allow for some approximation but the year-to-year uncertainty in manure analysis would not allow for more than a guess. However, measurement and comparison of the total P in the manured and control soils should allow a precise measure of added P by difference.

Conclusion

A large body of knowledge exists on phosphorus chemistry in soil and in water and this body of knowledge continues to grow worldwide. The older literature dealt largely with phosphorus-deficient plants and soils and the role of fertility management to increase agricultural productivity for the benefit of producers and society. The newer literature largely addresses current problems of phosphorus transfer from the soil to water, particularly with regard to the role of agriculture in the eutrophication of surface waters (Sharpley et al., 2000). The new knowledge sought here is: 1) the rate of transfer of P, both fertilizer and manure-derived, from the plow layer to subsoils over long periods of time, 2) the rate of transformation of "available" P to "unavailable" P over long periods of time under conditions relevant to Wisconsin agriculture, and 3) is whether or not the soil chemistry of phosphorus in a Wisconsin agricultural soil is sufficiently well-behaved that predictive models of long-term P levels and fluxes can be attempted. The knowledge sought is essentially of an applied nature that carries over into policies of permissible fertility management for the public good.

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Excess text

A set of fertility plots, both "organic" and "mineral", were established in 1962 at the UW Agricultural Research Station at Arlington, WI, by Prof. Emeritus Lloyd Peterson. Treatments included addition of solid dairy manure at a rate of 15 ton/acre/yr for 32 years and addition of phosphorus fertilizer, in the form of monocalcium phosphate ("triple superphosphate"), for 20 years. Since the retirement of Dr. Peterson and the cessation of treatment applications in 1994, these plots have been only minimally disturbed by continued cropping.