Manure P Sorption and Release in Semiarid Soils

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Abstract

The potential for P removal from surface-applied manure and its subsequent transport into adjacent bodies of surface or ground water is dependent on a number of factors broadly defined under 1) P loss potential due to site and transport characteristics, and 2) P loss potential due to management and source characteristics. The first factor assesses P transported off the field with runoff, leaching, and drainage water, and the second, quantity, availability, and forms of P at the site and the likelihood that this soil P (manure, and other sources) can present an environmental hazzard. This report focuses on the P source (manure) and soil chemical characteristic as measured by fertility indices and sorption and release of P in semiarid soils. Beef and hog manures were subjected to various P availability extractants singly and in combination with soils of varying reactive clay surfaces. The data showed that about 65% of the beef manure-P and 80% of the hog manure-P were inorganic, and that the bulk of this P could be extracted by the Olsen or Bray-1 procedure with water and 0.01 M $CaCl_2$ extracting significantly less P. When added to soils, P incorporation with wetting and drying cycles resulted in greater sorption of P than broadcast and immediate extraction. Soils with $CaCO_3$ also adsorbed more P than non-calcareous soils. Where disposal is required, application of manure not to exceed 90% of the soil P saturation value (P buffering capacity $\geq$ 10) on deep calcareous soils followed by incorporation on relatively level ground should minimize P removal from the site.

Introduction

The effects of animal manures on water quality have created public concern because of the potential for water pollution and subsequent fish kill and human illness (Levine and Schindler, 1989.). Invariably, the primary culprit in creating this adverse situation is an excess of manure-N and -P in the water (Duda and Finan, 1983). In most bodies of water, P is the limiting factor for these algal blooms and eutrofication to occur (Parry, 1998). Ideally, manure should be applied to soils in sufficient quantities to meet plant nutrient needs, but in most cases, meeting the N needs may surpass the P needs because of the greater need for N and a narrow N/P ratio in manures (Sharpley et al., 1998). In eastern Colorado, the potential exists for pollution problems to occur because of the need for disposal from the many beef feedlots and hog farming units in the area, along with municipal waste discharge. While we do not have huge bodies of water like the Chesapeake Bay area of the northeast, our rivers and tributaries, (South Platte, Republican) and ground waters can become contaminated, if large disposals are continuously carried out near them and on areas subject to erosion and leaching.

The objective of this study was to evaluate a beef and a pig manure source from eastern Colorado for their total amounts of P, the proportions of organic and inorganic P, and the release and sorption of this P in acid and calcareous soils from extractants of various conventional fertility indices used in the Great Plains. A secondary objective was to list and give a definition of the various P terms (P buffering capacity, P adsorption isotherm, P saturation index, Olsen P, etc) used in assessing soil P chemistry and fertility and the P Index which is being used extensively in most states as new research data come in. These definition will be given as an appendix at the end of the manuscript.

Materials and Methods

The manures were collected from lots near Akron, Colorado, and had been dried for some time, but were passed through an 850 micrometer sieve (20 mesh) before used for analyses. Table 1 gives pertinent properties of both manures. Analyses were conducted at a commercial laboratory.

The soils used were an acid (pH 6.2 to 6.8) to neutral surface soil (0-3 inches), and a calcareous (pH 7.8, 5% $CaCO_3$ content) subsurface soil (12-15 inches depth) of a Weld silt loam (fine, smectitic, mesic Aridic Paleustolls). An Ascalon sandy loam (pH = 6.0) was used also but only with a P adsorption isotherm evaluation with the other two soils. These soils were air-dried and passed through a 2-mm sieve. Soil organic carbon (SOC) contents (modified Walkley-Black ; Bowman, 1998) were 1.38% (13.8 g SOC/kg soil), and 0.86%, respectively, for the surface and subsoils, and 0.6% for the Ascalon soil. The subsoil contained slightly more clay than the surface soil.

Various extractants were used on the manure to quantify total P pools, and P pools extractable in water, 0.01 M $CaCl_2$, dilute acid (0.5 M H_2SO_4), and base (0.5 M NaOH and basic EDTA, Bowman and Moir, 1989), and anion-exchange resin strips. Fertility indices such as Olsen P (Olsen et al. 1954, and Bray-1 P (Bray and Kurtz, 1945) were also determined on the Weld soils with and without manures. P adsorption isotherm was determined in calcium chloride. P released and adsorbed were determined immediately upon P addition to the soil, and with incubated moist soils with two wet-dry cycles, with P left on the soil surface, and with P incorporated into the soil. An adsorption isotherm was also established with varying levels of pig manure in the subsurface calcareous soil.

Adsorption isotherms were determined using 5 g soil with varying amounts of P or manure (0, 20, 40, 60, 80, 100, 150 mg) and 50 mL of 0.01 M $CaCl_2$ with an equilibration time of 16 hr.

For all P analyses, an ascorbic acid reduction method (Murphy and Riley, 1962) was used for inorganic P (Pi) determination in the extract, and a persulfate oxidation method followed by ascorbic acid reduction (Bowman, 1989) for total P in the same extract. By difference we obtained organic P (Po).

Results and Discussion

A comparison of Table 1 showed that the pig manure contained more N (especially ammonium-N), Zn and Cu than the beef manure, but less K and Cl. Ash content and organic C were also different. These differences were probably a function of feed, litter, and storage.

The pig manure (1.9% P) contained much more total P than the beef manure (0.5% P) (Table 2). While about 35% of the P in the beef manure was organic, only about 20% was organic in the pig manure. Two methods proved useful in quantifying total manure P: one using concentrated sulfuric acid and 30% hydrogen peroxide, and the other a basic Na_2 EDTA extract. While the former method gave total P since organic P was oxidized by the peroxide, the latter method extracted both total Pi and Po. The dilute sulfuric acid method (1 h extraction) and a sequential acid then base extraction also gave relatively good recovery of P (85 to 95% of total). Calcium chloride gave the least recovery (10% of Olsen and Bray when corrected per g of manure), and water was intermediate. Nearly five times less inorganic P for the beef manure was extracted in calcium chloride than with water. These values were near equal for the pig manure.

Results from both manures for the fertility indices (Table 3) for both soils show the ineffectiveness of the Bray procedure in calcareous soils. For the surface soil with Bray, when beef manure was added, 67 % of the inorganic P was recovered. This value was 89 % for the pig manure. This large available P fraction in the pig manure was also verified by the resin-extraction procedure and water leachates (data not shown). The Bray procedure usually gives a larger value than the Olsen, and this is shown here also. However, the Olsen, as a basic extractant released more manure P. Almost 50 % more beef-P and 30 % more pig-P were extracted (Table 3). The Olsen procedure recovered essentially all the pig manure P (94 %) in both soils. For the beef, recovery was less (about 50 to 60 %).

Two adsorption isotherms were conducted to evaluate P retention in the soils (Fig. 2 and 3). In Fig. 1 various amounts of pig manure was added to the calcareous soil. The recovery of the manure P in calcium chloride (20, 60, 100, 150 mg manure) without soil was also determined. These values from manure were then used to calculate the amount of P adsorbed, and the P buffering capacity (PBC) which is the slope of the line relating adsorbed P(Q) and P in solution, I ($\Delta Q/\Delta I$). As more manure is added, less P becomes adsorbed (fixed), and the solution P increases until dQ/dI reaches 0 at maximum sorption. This value can be calculate , but the authors have arbitrarily chosen a value of 10 for the PBC under which problems of P movement may occur. The was reached with the 100 mg manure added to the 5 g soil, which is the equivalent of about 15 tons of pig manure per acre. As Fig. 1 shows, much more P is fixed with the calcareous soil. Similar results have been shown by many other studies (Sharpley, 1996; Sharpley and Sisak, 1997). Even with 150 mg manure (about 25 tons/acre) the line was still straight indicating a constant PBC of 35.

The second adsorption isotherm was run with inorganic P and with three soils. Adsorption was carried out immediately upon P application, and also after P incubation and wet-dry cycles. The data illustrate the relationship between texture and P adsorption, more reactive surfaces more adsorption. Again the data show how quickly a sandy soil saturates, and how much more difficult it is for one with calcium carbonate to become saturated (1 mg P/kg soil = 2 lb P/acre). From the data it appears that with 30 lb P, the Ascalon soil if immediately subjected to heavy rains afer manure application, could present P removal problems.

While soil test P is widely used to assess P removal hazzard, the adsorption isotherm with its PBC evaluation is still a very necessary tool.

Definitions:
Adsorption: Bonding of P ions or compounds to clay surfaces (usually a physical phenomenon).

Sorption: Same as above but can be physical or chemical.

Precipitation: Soluble P forming complexes as a function of pH usually with Fe, Al, and Ca.

Fixation: P is converted from a soluble or exchangeable form to one less soluble or to a nonexchangeable form. General term for all of the above.

Desorption: release of P form clay surfaces to the soil solution.

P quantity (Q) or capacity: amount of exchangeable P on the soil solid phase in equilibrium with the soil solution P. Measured as mg P/kg soil.

P intensity (I) or solution: amount of soluble P in the soil solution (very small pool) in equilibrium with solid phase. Measured as mg P/L.

P buffering capacity: measures the resistance of the soil system to changes in I (the slope of a Q and I relationship; ($\Delta Q/\Delta I$).

Threshold soil P: based on perceived soil P test levels above which could cause eutrofication from runoff.

Soil P saturation: percent saturation of available P to maximum P fixation.

P indexing tool: tool by NRCS and other state planners to rank vulnerability of fields as sources of P loss in surface runoff. Contains a transport and a source component.

P fertility index: Soil testing value for level of available P (low, medium, high) such as Olsen-P and Bray-1 P.

Resin-extractable P: anion-exchange resin beads or strip used as sink to fix P desorbed from a solid phase (soil, manure) into solution.

Available P: P that can be used by plants in a growing season (labile P). Usually P from a fertility index, P extractable in water or dilute calcium chloride, P on anion-exchange resins, or P (31) exchangeable with radioactive P (P-32). Available P measurements should always be accompanied by its method of extraction.

Organic P: P in crop residue, litter, grains, manures, and soil organic matter that cannot be measured directly without oxidation or chemical digestion (nucleic acids, phytates). Can be measured as total or partial in a given extract (0.5 M $NaHCO_3$; 0.5 NaOH; 0.5 M or 18 M H_2SO_4).

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