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PHOSPHORUS MANAGEMENT FOR LAND APPLICATION OF ORGANIC AMENDMENTS

Scientific Background

Introduction Recent increase in the number of confined animal feeding operations (CAFO) and other animal feeding operations (AFO) that generate significant amounts of animal waste has caused concern about management of phosphorus (P). This paper presents a brief scientific background of P behavior in soil and the views of Oklahoma State University soil scientists on management of P derived from land application of organic amendments (animal manure, biosolids, etc). These concepts are summarized in a recommended P management plan for land application of organic amendments. The management plan is based on three criteria: soil test phosphorus (STP), water soluble soil P threshold, and impairment status of watershed with regard to P. The plan requires knowledge of (i) level of P that provides a crop response, (ii) levels of water soluble P that are considered excessive (above threshold), and (iii) amounts of runoff P that results in unacceptable risk to surface waters. The level of P that provides a crop response has been documented from decades of agronomic research at OSU. However, knowledge regarding (ii) levels of water soluble P that are considered excessive (above threshold), and (iii) amounts of runoff P that results in unacceptable risk to surface waters is incomplete. Research is needed to provide information on these criteria. Without information on (ii) and (iii), the management plan proposed in this paper for soils already containing STP > 120 cannot be implemented. For this reason, we suggested applications of organic wastes be limited to a strong knowledge base (i.e. crop production based on STP) in an earlier publication (Johnson et al., 1998). Research is needed to provide a strong knowledge base on levels of soil test P that result in excessive levels of water soluble P and methods to determine unacceptable levels of P that may impact surface water quality.

Soil Test P and Crop Production Initial and ongoing field research over the past 30-50 years has led to reliably linking soil test phosphorus levels to crop production. Although there are some differences in procedures, each of the 48 contiguous states in the US commonly uses soil testing to identify when soils are deficient in phosphorus for crop production (Allen et al., 1994). An example of this soil test calibration from Oklahoma State University is shown in Table 1.

Table 1. P Soil Test Calibration for Wheat

Soil Test P (pp2m)	Percent Sufficiency	P_2O_5 lb/acre
0	25	80
10	45	60
20	80	40
45	90	20
65^+	100	0

Thus, when the phosphorus availability in a field is uniform and identified by a STP value of 65 or higher, there is no crop response to input (fertilization) of available P. Similarly, for a STP of 45, the calibration identifies a 10 % yield reduction if no P fertilization occurs.

Recent research (Goedeken et al., 1998; Raun et al., 1998) has documented extreme variability in STP over short (three feet) distances within fields may be common. Consequently, when a composite soil sample (Zhang and Johnson, 1997) has a STP value of 65 some portions of the field may still respond to P fertilization. Continued P-fertilization until the composite sample tests 120 will assure the lowest testing parts of a variable field will have a STP of 65 and no longer show a yield increase to P additions (Johnson et al., 1998). When the STP for a composite field sample is above 120, crops are not expected to benefit from continued P fertilization.

Conclusion 1. Phosphorus inputs will not be utilized to improve crop production when a field is identified by a composite soil sample to have a STP value of 120 or greater.

Soil Test P and Water Quality Environmental concerns regarding the P level of surface waters have not commonly been the primary research objective of soil scientists. OSU soil scientists have traditionally recommended no application of P-fertilizers after the STP reaches or exceeds 65 based on crop production. Research establishing the effect of soil test phosphorus on water quality in Oklahoma is in progress. Recent identification of nutrient "impaired" watersheds in Oklahoma did not have input from OSU soil scientists.

The implied relationship of soil scientists to water quality problems has resulted from the knowledge that soil scientists have defined criteria for nutrient management to grow crops. Since eutrophication and hypoxia result from nutrient enrichment of surface water, mismanagement of nutrients in crop production systems has been blamed for these water problems. With regard to nitrogen management, there is now strong scientific evidence to support this blame (Malakoff, 1998).

Soil scientists have clearly shown that the form of phosphorus (dissolved P or water soluble P) responsible for eutrophication increases in the soil immediately after P fertilization and then gradually decreases. They have also shown that water soluble-P increases in proportion to increasing STP (Johnson et al., 1998). From this, it is a logical deduction to conclude that risk of eutrophication increases with increasing STP, and that it is greater when STP is above 120 than when it is below 120.

Conclusion 2. P-fertilization increases the risk of water pollution. This risk is greater when STP is above 120 than when STP is below 120.

Water Soluble P. Phosphorus inputs that do not result in an increase in water soluble P should not increase risk to water quality. Phosphorus forms very insoluble compounds and has low water solubility in acidic (pH <5) and in calcareous (pH >7.5) soils (Bohn et al., 1985; Lindsay, 1979; Pierzynski et al., 1994). In addition, soils vary in their ability to retain P. Clay soils can adsorb more P than sandy soils (Zhang, et al., 1998a). Soil texture greatly influences water soluble P and will affect the solubility of land-applied manure P. Approximately 75 % of the P in feeds is present as phytic acid, a P-storage compound. Release of P from this compound, either in animals or soil, depends on the presence and activity of the enzyme phytase. Monogastric animals do not have the enzyme, hence much of the feed-P passes through them. Manure from these animals contains the P as phytic acid. The activity of phytase is pH dependent (Shieh et al., 1969), and may be low in calcareous soils. Thus, water soluble-P may remain at low concentrations in these soils when the continued P input is organic.

Conclusion 3. P inputs that no longer correct a soil-P deficiency for crop production may be environmentally safe if water soluble-P remains low (level consistent with STP of 120).

Best Management Practices (BMPs) and P in Water Runoff When water soluble-P is higher than the concentration normally found in soils that adequately supply P to crops, water quality may not be adversely affected if the field is not a source of surface water runoff. Similarly, there is no risk to surface water quality from continued input of P if the field is not in an "impaired" watershed, or if there are no neighboring bodies of water. These conditions commonly exist in arid regions (e.g. Oklahoma panhandle).

When water soluble-P is abnormally high it may not pose a risk to neighboring bodies of water if soluble-P in runoff is low. This condition may be created by using buffer strips and/or treatment of soil/field with P fixing material, such as water treatment residuals (Basta et al., 1998) to strip soluble-P from water as it leaves the field. Other conservation practices which reduce runoff and erosion can also reduce P loss from manured fields to surface waters.

Conclusion 4. Continued input of P to fields with high STP and water soluble-P are not a risk to water quality if there is no runoff, no neighboring bodies of water, quality of the water body is not limited by P, or the concentration of soluble-P is reduced to levels that do not result in unacceptable risk by buffer strips.

Management Strategies

The current scientific foundation for P-management is the soil test used to identify P needs for crop production. When STP levels are above the critical level for crop production (120), the environmental risk of continued animal waste-P input could be rationally managed by use of a water soluble-P soil test and implementation of BMPs. Management decisions regarding land application of organic amendments are discussed below and illustrated in Figure 1.

Case 1: STP < 120 Fields receiving organic amendments should be soil tested annually. If the STP value is less than 120, animal waste and other organic amendments can be applied at a rate to meet the seasonal nitrogen needs of the next crop to be grown. The nitrogen input from animal waste is determined from a realistic crop yield goal and takes into consideration residual nitrate-nitrogen identified in the soil test (Zhang et al., 1998b). Recent soil test summaries indicate 82 % of Oklahoma fields have a STP less than 120, and would qualify for this strategy.

Case 2: STP > 120 and Water Soluble Soil P < Threshold In this case, crops will not benefit from P inputs but may benefit from N inputs. The STP is above 120 but the water soluble-soil P is below the threshold level (to be determined from research studies) resulting in a low water quality risk providing erosion is controlled. Application of organic amendments to meet crop N needs should not pose undue environmental risk relative to P. Agronomic N rates can be applied in a non-P impaired watershed. However, organic waste applications should be limited in P-impaired watersheds. Additions based on agronomic N rate will increase STP and eventually create water soluble soil P levels above the threshold that may affect water quality in a P-impaired watershed. In a P-impaired water, BMPs that control erosion and reduce P-runoff should be used if organic waste is to be land applied. Waste applications are limited to amounts based on crop P removal (P removed in grain and/or forage). Applications that support multiple years of cropping are possible (i.e. one-time application that supports 3 years of crop P removal). No application of organic waste is recommended without incorporation of BMPs into the management plan.

Case 3: STP > 120 and Water Soluble Soil P > Threshold. In this case, crops will not benefit from P input (STP > 120) and increase water soluble soil P has the potential to increase risk to surface water quality (surface water that receives excessive P from surface runoff). Runoff P has the potential to adversely impact P-impaired watershed. Therefore, BMPs that control erosion and reduce P-runoff should be used if organic waste is to be land applied. Waste applications are limited to amounts based on crop P removal (P removed in grain and/or forage). Applications that support multiple years of cropping are possible (i.e. one-time application that supports 3 years of crop P removal). No application of organic waste is recommended without incorporation of BMPs into the management plan. The same recommendations apply to non-P impaired watersheds as a protective measure. These recommendations will limit P runoff and prevent non-P impaired watershed from becoming P-impaired watersheds.

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