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PHOSPHORUS RECOMMENDATIONS AND MANAGEMENT FOR OKLAHOMA

H. Zhang, J.G. Warren, C.J. Penn, J.A. Hattey, T. Ochsner, S. Deng, W.R. Raun, B. Arnall, B. Carter, C. Godsey, and K. Desta

Department of Plant and Soil Sciences
Oklahoma State University

Executive Summary

Significant progress was made in research toward managing phosphorus (P) for sustainable agricultural production and environmental protection in past decades. This article is intended to capture the new knowledge, and strengthen and update two previously published Production Technology publications: **PT 98-1 and PT-37** by the Department of Plant and Soil Sciences at Oklahoma State University (OSU). Soil test P for fertilizer recommendation in Oklahoma is expressed as an index (STP index) which is numerically equivalent to lb/acre (1.0 lb/acre in the top 6 inch soil is approximately equal to 0.5 mg/kg; the conversion is lb/acre = 2 x mg/kg or ppm). The STP index is used in this publication unless noted otherwise.

Livestock and poultry production in Oklahoma and neighboring states has created both economic growth and concern over the effects of excessive land application of animal manure on water quality in some areas. Land application of animal manure to meet crop nitrogen (N) needs increases soil P and has raised concerns about P losses from agricultural land and resulting environmental degradation of streams and reservoirs.

Most states in the US have developed standards or guidelines that limit manure applications to prevent excessive levels of soil P and to reduce water quality impacts. These guidelines may be P based so that manure is applied at rates sufficient to optimize crop yield or replace P removed by harvest. This prevents soil test P from building up to levels that are in excess of crop needs. Guidelines allow manure application rates sufficient to supply crop N requirement only when the risk of P transport to sensitive water bodies is low. Risk of P transport is generally assessed with a tool or index that predicts the potential for off-site transport to surface waters (Sharpley et al., 2003; Osmond et al., 2006;; White et al., 2008; White et al., 2009).

Decades of research revealed that a STP value of 65 is adequate for production of most crops. This agronomic threshold of STP 65 has been used by OSU to make fertilizer recommendations. More recent studies by soil scientists at OSU shows that a field-average soil test P index of 120 ensures the entire field has soil test P levels greater than

65, thus limiting the potential of localized agronomic P deficiencies and insuring that crop requirements met despite spatial variability. Applications of animal manure or other P-containing fertilizers to fields with soil test P levels that exceed 120 will likely have no benefits due to P, although the crop may benefit from N, organic matter, and other essential nutrients. Applying P to soils with a STP between 65 and 120 will reduce the probability of P deficiency occurring in the field. However, as the soil test P value from a composite field sample increases above 65 the potential response to P addition decreases, suggesting that it may not be economical to apply commercial P fertilizers. Therefore, OSU will not change its current recommendation of P application up to STP of 65. Considering soil test P levels alone will not suffice for assessing risk for P delivery to surface waters. Transport mechanisms and receiving water body sensitivity must also be considered.

Introduction

Management of animal manure in Oklahoma is receiving continued attention due to confined animal feeding operations as well as rise of environmental concerns. Historically, animal manures have been recycled by land application to agricultural fields as a beneficial input to crop production. Increased soil organic matter and plant available nutrients are recognized as the major benefits. We know that increasing soil organic matter affects soil properties that directly or indirectly affect crop production, although the impacts have been difficult to quantify. However, the relationship between increasing plant nutrient availability and their benefit to crop production has been a subject of widespread scientific inquiry for decades and is well documented. In the scientific process of improving the understanding of plant nutrient availability and crop response to these nutrients, much has been learned about the fundamental behavior of plant nutrients in the soil. This knowledge also provides a foundation for understanding how soil applied plant nutrients, from any source, might influence the environment.

General Soil-Nutrient Relationships

Phosphorus (P), and to some extent potassium (K), move much less readily in the soil compared to nitrogen (N). The relative immobility of P is a result of orthophosphate precipitation by calcium (Ca) in soils above pH 5.5 and precipitation/adsorption by aluminum (Al) and iron (Fe) in soils below pH 5.5. Inorganic N is mobile in soil because most of the inorganic N is quickly transformed into the non-precipitating nitrate (NO_3) form. Inorganic N results from the mineralization of organic-N or from the application of fertilizer. Consequently, because N is required in the greatest amount for crop production and since N is relatively mobile in the soil, N management is directly related to crop yield. This is why N typically must be applied on an annual basis to many non-leguminous crops. On the other hand, P is needed in lower amounts by plants and only a small portion of the total P concentration in soils is plant available. As a result, producers are able to “build up” soil P concentrations, eliminating the need to apply P on an annual basis.

Plants can only extract immobile nutrients from a thin layer of soil surrounding the root. The total amount of inorganic P and K present is not as important as the concentration of these elements in the soil next to the root surface and the capacity of that soil to replenish

P and K in the soil solution when it is removed by plant uptake. Soil tests have been developed to provide an index (e.g., Table 1) of the soil's capacity to supply adequate amounts of these nutrients during the crop growing season. Recommendations for other crops are summarized in Zhang et al. (2009). In addition to identifying the soil-P condition where deficiency is likely to occur (soil test index < 65 or 32.5 ppm) which is considered the agronomic threshold, scientists have also calibrated the soil test to identify probable yield (% sufficiency) when the deficiency exists, and the amount of fertilizer (expressed in P_2O_5) required annually to correct the deficiency. The soil test P (STP) index is produced using the Mehlich 3 (M3) extraction procedure in Oklahoma. This extraction method has been adopted by many other states for estimating plant available P.

Table 1. Calibration of Mehlich 3 soil test P for wheat grain production in Oklahoma

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

Crop Response to Fertilizer P

Soil test calibrations, such as Table 1, were developed for Oklahoma and many other states more than 30 years ago and involved replicated fertilizer rate experiments at agricultural research stations and on farmers' fields over broad geographic regions. Current soil test calibrations do not differ markedly from one state to another when similar testing procedures and reporting units are used. It has been consistently demonstrated that soil testing can be used to identify deficiencies and recommend the appropriate amount of fertilizer-P which results in increased plant-available-P in soil. Three long-term phosphorus research experiments at Oklahoma State University (OSU) Agricultural Experiment Stations near Lahoma, Stillwater, and Haskell showed soil-P accumulation upon annual fertilizer-P application of 0 to 80 lb/acre for continuous winter wheat production (Figure 1, Zhang et al., 2005).

The 0.07 slope for the “All Soils” regression line in Figure 1 indicates that approximately 14 lbs/acre of fertilizer P_2O_5 would be required to increase M3-P index by 1.0 under normal wheat production practices. In other words, a net change of about 14 lb P_2O_5/acre is needed to raise (fertilizer-P input) or lower (crop-P removal and other losses) the soil test P index value by 1.0. It is quite possible to increase STP above the agronomic threshold by simply adding P fertilizer or animal manure, but Figure 2 shows higher yields generally do not result from P application when STP is greater than 65.

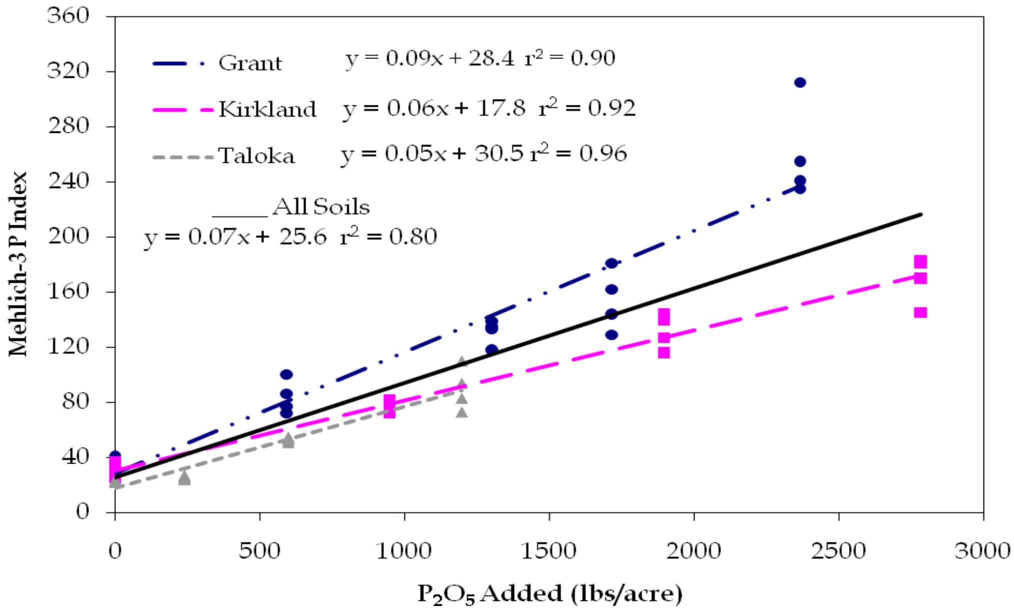

Figure 1. The relationships between Mehlich 3 P and P added for three Oklahoma agricultural soils and all soils combined.

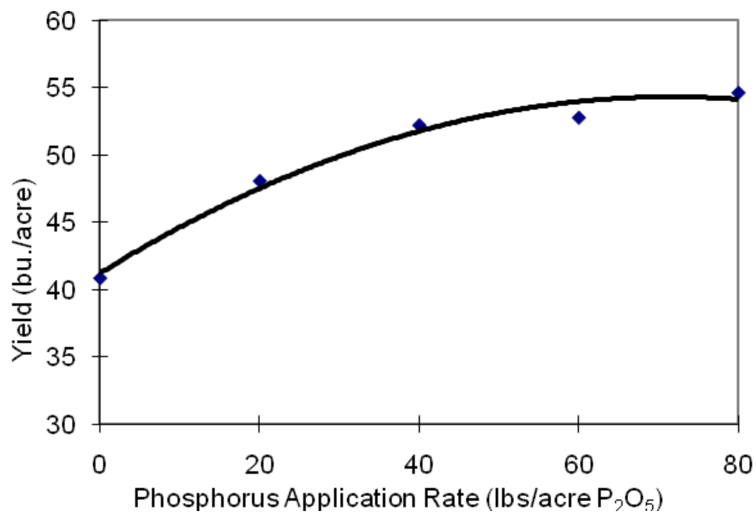

Figure 2. Relationship between winter wheat grain yields and P fertilizer application rate from a long-term fertility study conducted near Lahoma, Oklahoma. Soil test P at 20 lbs/acre/year P_2O_5 was below 65 and thus the yield increased significantly with P application. Soil test P at 40 lbs/acre/year P_2O_5 was about 65 and the yield increased slightly with P application. However, no yield increase was observed when soil test P values were above 65 (i.e., the 60 and 80 lbs/acre/year P_2O_5 application rates).

Sometimes crop yield responds weakly to inputs of fertilizer-P even when soil test P is less than 65 as illustrated by Figure 3. This study of alfalfa yields in relation to fertilizer-P was conducted at Central Oklahoma Research Station near Chickasha. The initial soil test

P index averaged 30 (80% sufficient), but was quite variable. Addition of as much as 600 lb/ac fertilizer-P increased yield less than 1 ton/acre.

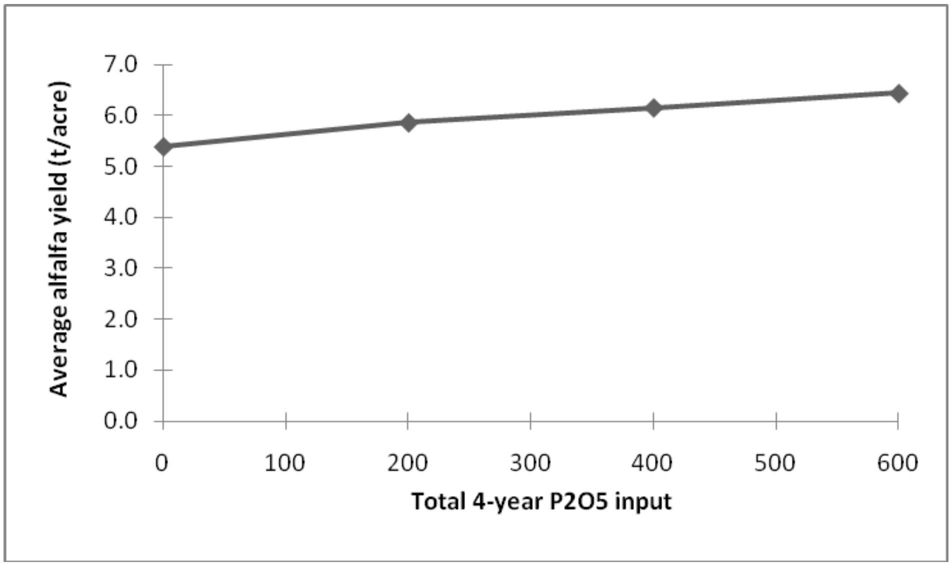

Figure 3. Alfalfa yield response to high rates of fertilizer-P in a P deficient soil (STP=30) at Central Oklahoma Research Station near Chickasha.

Field Spatial Variability of Soil Properties

Soil properties vary greatly in space and time due to anthropogenic and natural disturbances. Absence of tillage in pastures and also the irregular deposition of cow dung and urine contribute to soil nutrient variability. This variability could be spatial (i.e., across the land surface), or temporal (from year to year). Figure 4 shows the horizontal variability of soil test P for a pasture in eastern Oklahoma (Kariuki et al., 2009). STP ranged from 86 to 270 in a 15-acre field. A composite soil sample consisting of 15-20 cores following the recommended procedure would give a STP of approximately 110 for the whole field. Therefore, certain areas of the field would have STP below the average value.

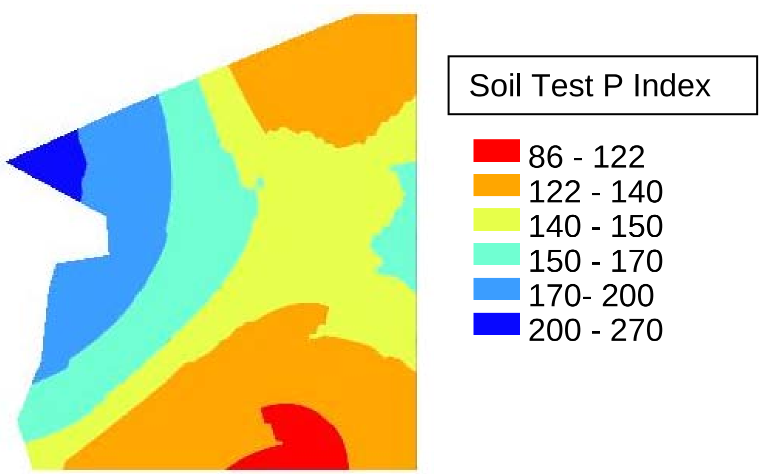

Figure 4. Spatial variability of soil test phosphorus index for a 15 acre pasture in Delaware County, Oklahoma.

Research evaluating soil test variability within fields has shown that a composite of 15 to 20 core samples (0 to 6 inch depth, obtained by the OSU-recommended procedure) would leave some areas of the field lower than 65 when the average STP is at or slightly above 65. In order to eliminate all deficiencies for the entire field it would be necessary to vary application rates across the field (such as using grid soil sampling and a variable rate fertilizer applicator) or exceed the 65 limit with uniform application. It has been shown that the STP value, for a composite sample from a variable field, needs to be about 120 to ensure that none of the field is P deficient (see Figure 5, data from Gordon Johnson). However, this number may vary slightly depending on the degree of spatial variability of the field. The 3 fields evaluated had no deficient areas (STP>65) when the average STP reached 95, 100 and 115. Therefore, in some cases it may be justified to apply manure or other organic-P amendments until the composite STP reaches about 120, thereby eliminating P deficiency.

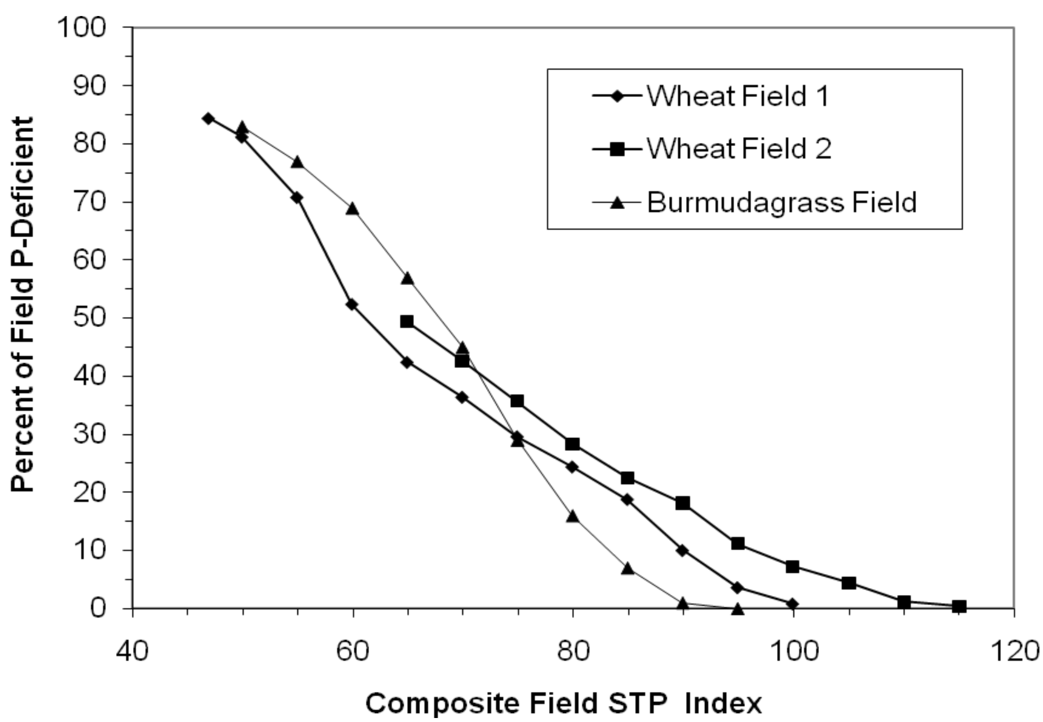

Figure 5. Calculated percent of field that would be P-deficient as the composite soil test P index value increases from the determined STP for 3 variable fields. The percent of field P-deficient was calculated by the number of 250 small grids in each field had STP less than 65 at elevated whole field composite STP until no grid was below STP 65. The 3 fields used for this analysis were 2 continuous wheat fields and one bermudagrass pasture.

However, Figure 5 also indicates that as the soil test P value from a composite field sample increases above 65 the probable response to fertilizer P addition decreases (i.e. slope of the line decreases), suggesting that it may not be economical to apply commercial P fertilizers. The weak yield response when STP is greater than 65 is also validated by data in Figure 2 and 3. Therefore, OSU will not change its current P recommendation up to 65 STP.

Effect of Excess Soil-P on Runoff P

One of the effects of increasing soil test P is that soil solution P or water soluble P also increases proportionately (see Figure 6). The increase of water soluble P may be directly linked to the dissolved reactive P in runoff. This has been documented by many recent rainfall simulation studies (e.g., Zhang et al., 2005). Therefore, the higher the soil test P level is, the higher the risk of P movement to receiving water bodies.

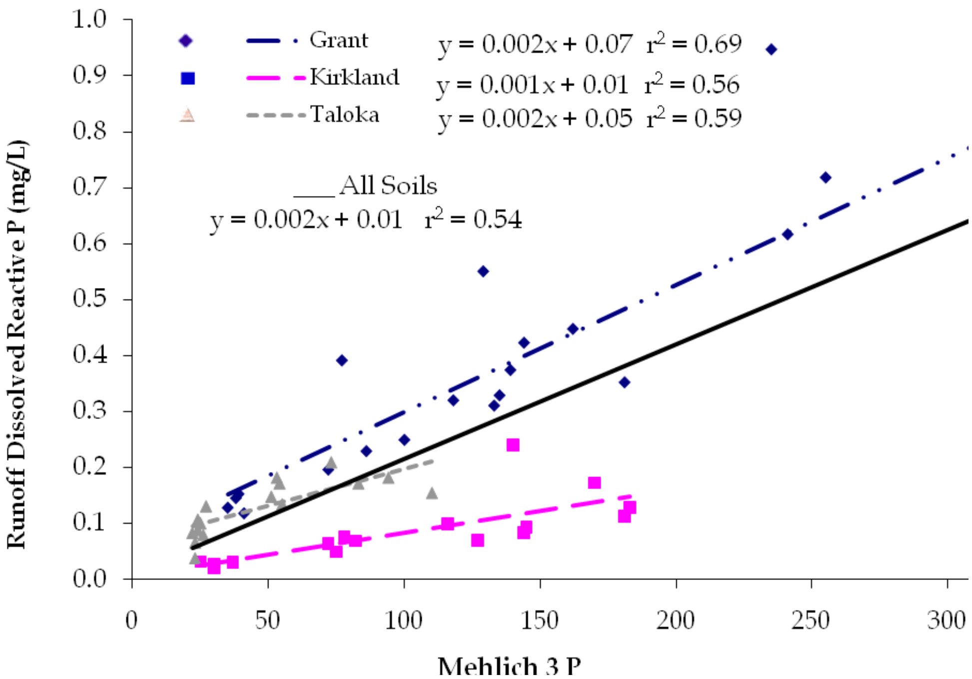

Figure 6. The relationship between dissolved reactive P in runoff and Mehlich 3 soil test P from 3 different soils in Oklahoma. Data collected from plot studies under simulated rainfall.

Because the concentration of water soluble P in soils increases at different rates in different soils (see Figure 6), some states have called for basing manure applications on the direct measurement of water soluble P. However, agreement among states on universal soil tests or critical levels has not been reached. Furthermore, the soil test-P or water soluble-P number is not adequate to determine the environmental risk of offsite impact. Some degree of environmental impact is possible even from soils with P concentrations that do not exceed recommended crop production levels. Some consideration of P transport mechanisms and biological availability, as well as the sensitivity of receiving water bodies is needed. Thus, the environmental impact from STP will be watershed dependent based on differences in soils, in stream processes, and the sensitivity of receiving water bodies to P loading. Use of an environmental soil test P threshold level based on crop requirements will require risk-based decisions that consider transport mechanisms (hydrology), characteristics of the receiving surface water body, and water quality standards.

Management of Soil-P Inputs

When management of P inputs to soils is considered, two clear outcomes are of concern. First, there is the traditional management of P inputs to improve crop production related to the needs for food, feed, and fiber. Input rates are usually small because of economics when commercial fertilizer is used. Second, there is the recent concern to manage P inputs to minimize risk to surface water quality. Guidelines for P inputs related to crop production are clearly defined by scientific research. When soil test P values are below 65, inputs of P according to soil test calibration are prudent for increased crop production. When STP levels in fields are known to be highly variable, crop yields may be further increased by inputs of P until the composite soil test P value reaches about 120. When P inputs, in the form of animal manure are managed with the interest of balancing the benefits of food production against risk to the environment, a STP value of 120 serves as a maximum value above which P is no longer beneficial for crop production. Figure 7 shows that organic P sources such as poultry litter can serve as an excellent source of plant available P and continuous addition beyond plant needs can increase STP values. The rate of STP increase with different forms of P addition may vary somewhat based on soil types and location.

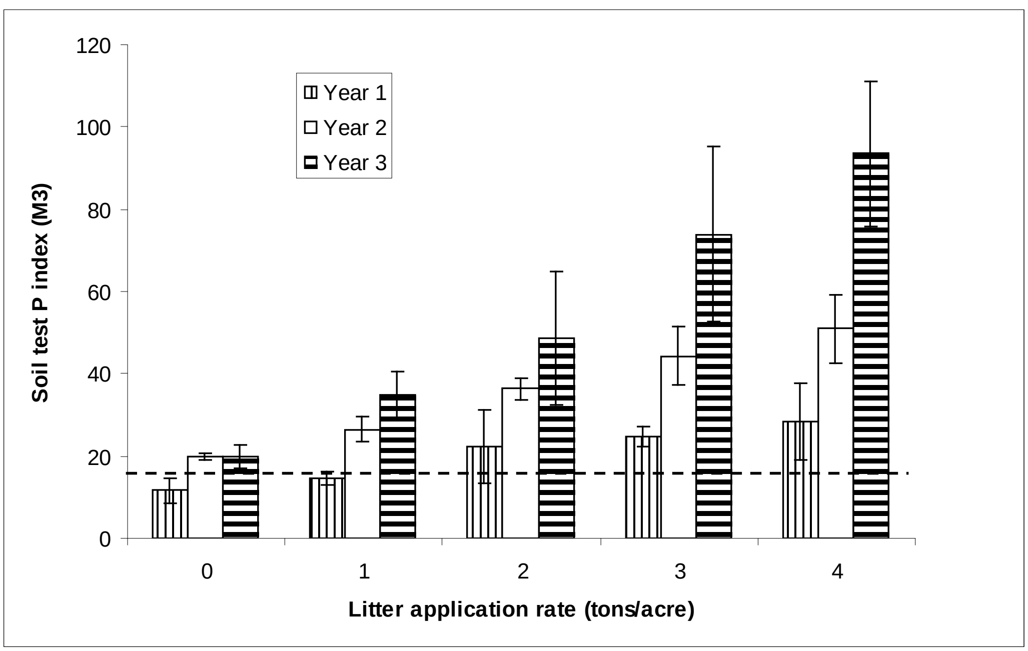

Figure 7. Changes in soil test phosphorus index (Mehlich 3 P at 0-6 inch depth) on bermudagrass hay field after 1, 2, and 3 years of poultry litter application at the Eastern Agricultural Research Station near Haskell, OK (C. Penn, unpublished data). Dashed line represents the background composite soil test phosphorus value for the entire field prior to litter applications (index value of 16).

It is known that even in cases where STP is beyond 120, the organic matter, nitrogen and other nutrients supplied in animal manures are still beneficial to crop production. Therefore, these benefits must be weighed against the increased risk to water quality. The potential for P loss from land to a receiving water body not only depends on the magnitude of the source factor (P management and STP) but also on transport mechanisms (hydrology, rainfall, slope, etc.). Therefore, a risk based management tool that takes both the source magnitude, transport and management into consideration is needed to determine organic byproduct land application.

In summary, we believe consideration of soil test P levels alone will not suffice for assessing risk for P delivery to surface waters. A comprehensive field validated assessment tool is needed to determine organic amendment application rates.

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