The Potential for Plants to Remove Phosphorus from the Spodic Horizon[1]

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This publication is part of a series titled ***Soil Phosphorus Storage Capacity (SPSC) for Phosphorus Risk Assessment and Management.*** The series is intended for use by soil scientists, environmental consultants, state agency personnel, Extension faculty, and others who are interested in management practices and policies that minimize the risk of phosphorus loss from soils.

Introduction

Continuous application of phosphatic fertilizers to Florida's agricultural lands has increased soil phosphorus (P) content with time, which often results in soils becoming heavily P-impacted. Phosphorus accumulation in soils has increased the potential for P loss to surface waters, potentially contributing to eutrophication. Sandy soils, which are prevalent in Florida, have lower P-retention capacity than finer-textured soils. Thus, the risk of P loss from sandy soils tends to be high relative to other soils. This publication describes the P-release potential from subsurface horizons of Spodosols, the dominant soil order of Florida covering approximately 8.4 million acres (20% of the land surface) in the state.

Spodosols have sandy A and E horizons with little P-retention capacity; below the A and E horizons is the Bh or spodic horizon, which has a high P-retention capacity relative to most sandy horizons (for more information, see Nair et al. 2011, SL357/SS558 *The Long-term Contribution of Phosphorus from Agricultural Lands to Lake Okeechobee*; https://edis.ifas.ufl.edu/ss558). Vertical movement of P through the soil profile results in its contact with the Bh horizon. The spodic horizon of a P-impacted soil can serve as a P source well before the soil reaches its maximum retentive capacity, resulting in the upward diffusion of P into overlying soil. The specific objective of this publication is to evaluate the potential for plant roots to remove P from the spodic horizon. In this article, we provide examples of land-use systems where P is removed from lower soil horizons by deep-rooted trees. This information will be useful for soil scientists, environmental consultants, state agency personnel, Extension faculty members, and others interested in using phytoremediation (removal of P using plants) as a best management practice (BMP).

Understanding the Risk of P Loss from the Spodic Horizon

During Florida's rainy season (June to September), the water table is typically above the spodic horizon, resulting in little or no downward movement of water through this horizon. Given these conditions, P released from the Bh could diffuse upward into the overlying E horizons, which have little or no capacity to hold P. As the water moves laterally through the E horizon, water will transport this P to ditches and adjacent water bodies. It is important to evaluate the potential for P transport by this method in

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those situations where spodic horizons have been heavily impacted with P added through animal manure or commercial fertilizer application. The risk of P loss from a soil can be evaluated using the recently developed techniques of **P saturation ratio** (**PSR**; for more information, see Nair et al. 2010, SL333/SS539 *An Indicator for Risk of Phosphorus Loss from Sandy Soils*; https://edis.ifas.ufl.edu/ss539) and the **soil P storage capacity** (**SPSC**; for more information, see Nair et al. 2010, SL336/SS541 *Understanding Soil Phosphorus Storage Capacity*; https://edis.ifas.ufl.edu/ss541). The PSR refers to the molar ratio of P to [Al+Fe]), whereas SPSC is a measure of the amount of P a soil can hold before the soil becomes an environmental concern.

The PSR and SPSC values of a soil can be calculated using P, Fe, and Al in an oxalate, Mehlich 1, or Mehlich 3 extracting solution (Nair et al. 2010; https://edis.ifas.ufl.edu/ss541). In this article, oxalate P, Fe, and Al were used to calculate the PSR (PSR_{Ox}) and SPSC. A "change point" at which water-soluble P (WSP) abruptly starts to increase with increasing PSR can be used for management purposes to evaluate the potential risk of P loss from soils. The change point corresponds to a threshold PSR value above which any added P may be lost easily through runoff or leaching.

For the spodic horizon, PSR_{Ox} and SPSC were calculated using the following equations:

PSR_{Ox}= (Oxalate-P/31) / [(Oxalate-Fe/56) + (Oxalate-Al/27)] Eq. 1

SPSC= (Threshold PSR_{Ox} – Soil PSR_{Ox}) * Oxalate-[(Fe/56) + (Al/27)] * 31 (mg/kg) Eq. 2

Note: To convert SPSC from mg kg^{-1} to kg ha^{-1}

SPSC in kg ha^{-1} can be easily calculated using Eq. 3.

SPSC (kg ha^{-1}) = [SPSC (mg kg^{-1})]*[(Thickness of the soil horizon (m)*BD (kg m^{-3}))/100] Eq. 3

Here BD represents the bulk density of the corresponding horizons. For example, the bulk density of a typical spodic horizon is 1,480 kg m^{-3} (1.48 g cm^{-3}).

How do we evaluate plant P availability?

The iron oxide (FeO) impregnated filter paper technique has been successfully used to generate an index of plant P availability and the release of P from soil (Chardon et al. 1996). The FeO coating acts as a P sink and simulates the adsorption mechanism that takes place at the interface of soil and root surface. Correlation of FeO-P with plant response has been better than that of traditional tests in soils fertilized with slowly water-soluble phosphate rock (Menon and Chien 1995). However, this procedure is not intended to substitute for standard soil testing but rather should be used to assess the potential of plants to remove P from a soil horizon.

What is the relationship between plant P availability and P release from the spodic horizon?

Manure-impacted Bh horizon samples were extracted using iron-oxide impregnated filter paper, and the relationship between FeO-P and PSR was evaluated. Plant P availability, as inferred from FeO-P, increased considerably when PSR was greater than the threshold value of 0.05 for spodic horizons (Chakraborty et al. 2011) (Figure 1). Therefore, plant P availability from the spodic horizon is minimal when SPSC is zero or positive, and it increases with negative SPSC (Figure 2); it follows the same trend as the SPSC/WSP relationship (Nair et al. 2010; https://edis.ifas.ufl.edu/ss541). Therefore, plants can take up P from spodic horizons as observed by Ibrikci et al. (1994), and the total amount of P that can be removed will be proportional to negative SPSC (Figure 2) to the extent of root proliferation. As long as SPSC of the spodic horizon is positive, plant availability of P from the horizon is much less. However, if the SPSC values of the E and A horizons are negative, plants will be able to effectively remove P from these horizons.

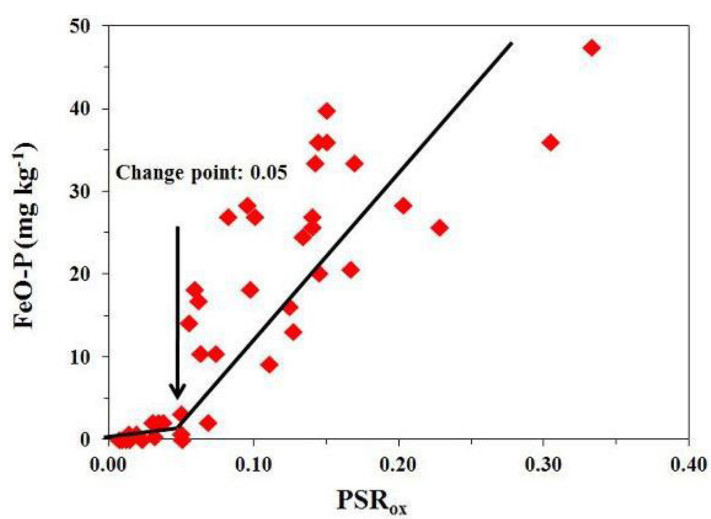

Figure 1. Relationship between P extracted from iron-oxide impregnated filter paper (FeO-P) and P saturation ratio calculated for the spodic horizon using P, Fe, and Al in an oxalate extract (PSR_{ox}).

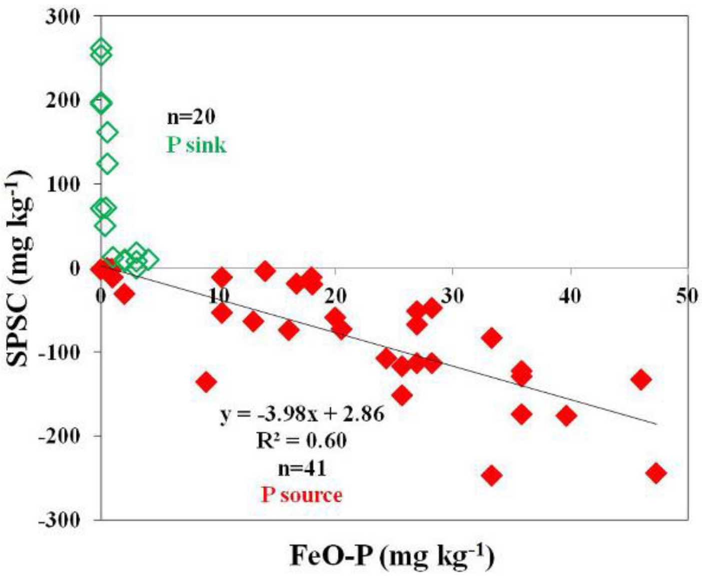

Figure 2. Relationship between SPSC and P extracted from iron-oxide impregnated filter paper (FeO-P) for Bh horizon soils. Open (green) and closed (red) markers represent positive and negative SPSC respectively. The R^2 value is for soils with negative SPSC.

Can deep-rooted trees help remove P from subsurface horizons?

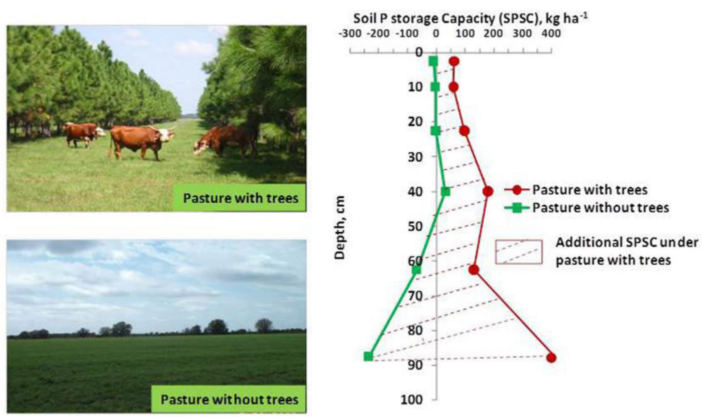

Figure 3. Comparison of the SPSC of soil profiles to a meter depth in a pasture with trees vs. a bahiagrass pasture without trees. The profiles depicted are representative of the two conditions (with and without trees) based on random sampling within each pasture type.
Credits: from Nair et al. (2007).

One possible management strategy for P-enriched soils is mining of soil P, which includes using a crop grown without external P application as a means of “harvesting” P from the soil. Phytoremediation is an inexpensive and highly effective technique to reduce the amount of P loss through surface or subsurface flow. Plant-based cleanup strategies offer a number of advantages compared to traditional cleanup methods. Since deep-rooted plants can access P from spodic horizons, soils under trees such as pine could be less susceptible to P loss compared with those soils under treeless bahiagrass pastures as shown at this Spodosol site in Hardee County, Florida (Figure 3).

The SPSC values for the various horizons may be added across a soil profile to obtain a single value for any specified soil depth (Nair et al. 2011; https://edis.ifas.ufl.edu/ss558). Total SPSC to a meter depth at a pasture with trees established for 15 years was 1,500 kg ha^{-1} compared with 370 kg ha^{-1} for an adjacent treeless pasture (Nair et al. 2007). The above finding indicates that P removal by trees results in the capacity of these soils to retain more P in comparison to a pasture without trees. Any P held loosely in deeper horizons moves to the surface as the water table rises, and P could be removed by vegetation with shallower rooting systems as well.

A few other examples of SPSC comparisons between pastures with and without trees are illustrated in Table 1 (Michel et al. 2007). Two of the study locations are on Spodosols and the other two on Ultisols. Recent work (Chakraborty 2011) indicated that P can be taken up by plants from the Bt horizons of Ultisols provided root penetration and proliferation in the horizon are possible.

The general trend in SPSC from pastures with and without trees at the locations in Table 1 is similar to that at the Hardee site. The SPSC is significantly greater in soils in tree-based systems compared with those adjacent sites without trees, except at the Osceola site where there was considerable P storage capacity left (high positive SPSC) to 1 meter depth for pastures with and without trees. Phosphorus can be removed from all locations within a soil profile by deep-rooted trees (or other deep-rooted plants), facilitating P removal from lower depths, including the spodic horizon. Hence, phytoremediation techniques should be feasible for removing P from deeper soil horizons for Florida soils where P release is regulated by Fe and Al. A flowchart illustrating the use of SPSC as a tool in assessing applicability of phytoremediation as a possible technique to mitigate P loss is shown in Figure 4.

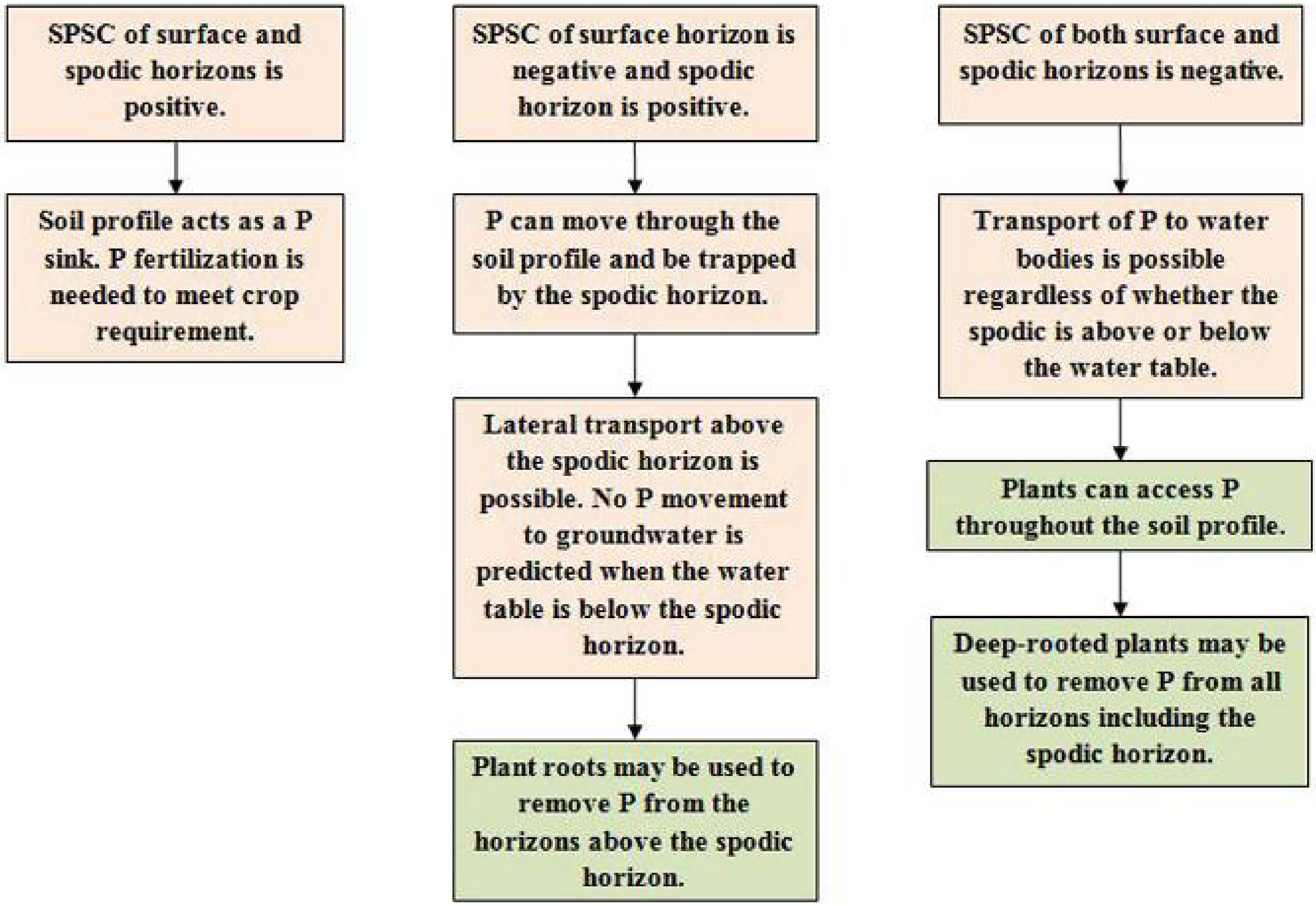

Figure 4. Flowchart illustrating the applicability of SPSC in predicting P loss risk from surface and subsurface horizons of Spodosols. When SPSC is negative, removal of P from a soil horizon may be accomplished by growing plants that are able to remove P from that horizon.

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Table 1. Differences in SPSC at four sites in Alachua, Suwannee, Manatee, and Osceola Counties in Florida in pastures with and without trees on Spodosols and Ultisols.

Location, soil order, and years since tree establishment	Treatment	SPSC (kg P ha^{-1})
Alachua County	Pasture with trees	-36
Ultisol; 8y	Pasture without trees	-542*
Suwannee County	Pasture with trees	342
Ultisol; 40y	Pasture without trees	-60***
Manatee County	Pasture with trees	329
Spodosol; 12y	Pasture without trees	191**
Osceola County	Pasture with trees	657
Spodosol; 12y	Pasture without trees	926^{NS}

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively; NS = not statistically significant.
Adapted from Michel et al. (2007).