Fate of Phosphorus in Everglades Agricultrual Soils after Fertilizer Application[1]

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Introduction

Land use changes and cropping practices in the Everglades Agricultural Area (EAA) of south Florida may alter soil conditions and organic matter decomposition and ultimately influence the fate of phosphorus (P). Soils of the EAA contain approximately 85% organic matter, and developed under P-limited wetlands subjected to flooding for most of the year. Cropping systems in the EAA require a wide range of P inputs, with application rates of 0-290 lb P_2O_5 per acre for sugarcane and vegetable crops. Cultivation practices, such as tillage, result in incorporation of bedrock limestone ($CaCO_3$) into the surface soil, which increases P retention and decreases its availability to crops. All of these factors contribute to decreasing the soil depth to bedrock, and increase the potential for incorporation of limestone into the root zone of crops. As the amount of limestone increases in the surface soil, additional P fertilization is required to satisfy crop nutrient requirements because of the loss of P to reactions with the limestone. Consequently, there is a need to determine the fate of applied fertilizer P for these changing soil conditions.

Phosphorus is present in soil in various forms, only a few of which are considered plant available. Five general forms of P include the plant-available pool, iron-aluminum bound P, calcium-magnesium bound P, humic-fulvic acid P, and residual P. These latter two pools contain P in organic forms, such as undecomposed plant material and peat. Upon decomposition, this pool contributes to plant-available P. Plant-available P comprises the smallest pool, but it can be taken up by plants. It is desired that most of the applied fertilizer P ends up in this pool for crop uptake. However, plant-available P reacts with exchangeable base cations, such as calcium, magnesium, iron, and aluminum, which renders it temporarily unavailable to crops. The mixing of limestone into soils by tillage increases the concentrations of these cations, especially calcium, which decreases the persistence of plant-available P after fertilizer application.

This document focuses on organic soils in southern Florida and their management to improve crop production while also reducing adverse environmental effects. This publication describes factors that influence P transformations in organic soils used for crop production, and recommends management strategies to increase P utilization efficiencies for crop production while minimizing nutrient export from fields, especially during times of land use change. The target audience for this publication includes growers within the EAA, state and federal personnel dealing with organic soils in southern Florida, researchers, and Certified Crop Advisers or other consultants making fertilizer and amendment recommendations.

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The EAA

The 700,000 acres (280,000 ha) of the EAA is characterized by subsiding organic soils (histosols) underlain by limestone bedrock. These organic soils developed under low nutrient status, which supported vegetation adapted to these conditions, primarily sawgrass (*Cladium jamaicense*). Due to conversion of this ecosystem to agricultural use, the dominant land use became annual crops of winter vegetables and sugarcane (*Saccharum* sp.) in the early 1900s.

Most acreage of organic soils in the EAA fall within three soil series: Dania, Lauderhill, and Pahokee. The primary differences between these classifications are the depth to bedrock, with the Pahokee series having the deepest soil and Dania the lowest. The Dania muck with depth to bedrock of 19 inches (45 cm) is typical of the increasing type and condition of soils within the EAA. It is important to determine how the mixing of bedrock limestone into soils influences the behavior of P fertilizers after their application. To accomplish this task, P fertilizers were applied to typical cultivated soils and also to soils that have never been fertilized or extensively tilled. The changes in P concentrations over time were then compared between the two land uses, with differences being attributable to the impacts of cultivation practices. Once effects of cultivation practices on persistence of P in soil are determined, we can better understand how to adapt fertilizer management to changing soil conditions.

Cultivated vs. Uncultivated Soil Characterization

Cultivation to sugarcane significantly influenced soil physical and chemical properties. Tillage has mixed some of the underlying limestone into the surface soil, significantly increasing soil pH and P distribution in both the organic and inorganic fractions. Additional dissolved limestone was brought to the surface due to upward movement of water, and subsequently deposited within the surface soil layer after evaporation.

The water-holding capacity decreased with cultivation, likely resulting from destruction of soil structure by tillage (Table 1). The total carbon and nitrogen content did not differ between land uses, but available nitrogen was higher for uncultivated soil. Since nitrogen fertilizers are seldom applied for sugarcane production in the EAA, lower nitrogen concentrations in the surface horizon could be expected. Nitrogen originally in the organic materials that make up the soil is converted (mineralized) to inorganic forms as subsidence progresses. It is this mineralized nitrogen that satisfies the crop nutrient requirement for crops, and that is effectively removed from the soil by the crops.

Phosphorus Distribution in Soil

Soil total P was higher for the sugarcane soil (Table 1) as a result of years of historic P fertilization. Due to the short growing season for most vegetables, P fertilizer is used more extensively for vegetables than for sugarcane. Additionally, high P uptake by sugarcane is problematic since excessive P interferes with sugar production. Thus, sugarcane typically receives low rates of P fertilizer, usually based upon recommendations offered after soil testing. One should keep in mind that some of the P fertilizer added over the last 50 years of cropping is bound to calcium and made unavailable to plants, while another portion is removed from fields via the harvested biomass. Only a small fraction remains in the soil, which is the difference (268 ppm P) between the uncultivated soil P and the sugarcane soil P.

The P distribution in soil varied between land uses, with sugarcane having more P in inorganic pools while the uncultivated soil had more in organic pools. Cultivated soil had 53% of the total P in inorganic fractions, but uncultivated soil only 19%, with the differences between land uses attributed to P fertilizer addition to sugarcane as well as potential differences in organic P mineralization between land uses. Total inorganic P was 265% higher for sugarcane than uncultivated soil, but organic P was higher for the uncultivated soil (781 ppm) than sugarcane (577 ppm).

Changes in Plant-Available P after Fertilizer Application

Water-soluble P concentrations in soil increased with increasing fertilizer application rates for all sampling times and both land uses. However, concentrations in uncultivated soil increased proportionally to P-fertilized soil due to organic P mineralization. At all sampling times, plant-available P concentrations remained higher for uncultivated than sugarcane soil. Lower P concentrations for sugarcane were related to adsorption by mineral components (e.g., limestone). Cultivated soils have higher calcium concentrations resulting from incorporation of bedrock limestone into soil by tillage, which increased pH and fostered sequestration of plant-available P into stable calcium-bound P pools. This greater P retention for sugarcane was reflected in the greater proportion of P in inorganic pools compared to uncultivated soils.

The uncultivated soils have higher iron levels, which sequesters P as ferric phosphate and decrease its availability. However, most of the P in uncultivated soils is in organic form (81%), thus its availability in this soil is more dependent on organic P mineralization. Uncultivated soil exhibited an 11.5 ppm increase in plant-available P from 0 to 21 days after fertilizer application. In contrast, plant-available P only increased 3.3 ppm for sugarcane during this time span. Over time, lower plant-available P reflects greater P retention, thus, the organic P mineralized may be rapidly sequestered in unavailable forms for sugarcane soils. The greater persistence of P in uncultivated soils suggested less P retention by precipitation and adsorption reactions.

The percentage of applied P recovered in plant-available pools 1 day after fertilizer application averaged 1.7 and 2.0% for sugarcane and uncultivated soil. Cultivation decreased the proportion of applied P recovered in plant-available forms at all application rates, suggesting that P is removed from plant availability rapidly due to the presence of base cations moving up the soil profile with changes in the water table. In effect, as this process continues, more P will be needed to grow sugarcane in the future.

Everglades Restoration and Wetland Creation

Some lands within the Everglades Agricultural Area, including wetlands and seasonally-flooded prairies, are being reclaimed for water quality purposes. However, long-term effects of fertilization and cropping practices described in this document indicate that direct conversion from active farming, such as from sugarcane production directly to wetlands, may be problematic due to the changes in nutrient dynamics that may occur. The shift directly to wetlands may, in fact, release considerable amounts of P into the Everglades, thwarting the intent of the land use change. The inorganic P component in sugarcane soils may lead to the regeneration of soluble P in frequently flooded land uses such as wetlands.

Flooding would cause organic matter accretion, thereby increasing P retention and stabilizing P in organic pools. Thus, soils that have a high proportion of total P in organic forms would be less prone to release P and enrich nearby aquatic systems. Flooding has the opposite effect for mineral-associated P since dissolution of P in inorganic pools occurs after flooding. Therefore, sugarcane soils would likely be sources of P if converted directly to wetlands, which may cause harmful effects to the Everglades ecosystem including eutrophication of surface waters and alteration of the structure and function of vegetation and microbial communities.

To avoid such undesirable discharge of P into the Everglades ecosystems, a transition from sugarcane land to wetlands through seasonally-flooded prairies may assist with chemical and biotic conversion of inorganic P forms to the more stable organic forms, aided by the intermittent flooding and drying that is a major component of wetlands in Florida. Once this transition has occurred, further land use changes to wetlands can be accomplished without observing large releases of inorganic P that will occur if the sugarcane-to-wetlands changes were made without the temporary transition to wet prairies.

Conclusions

Agricultural drainage and conventional cultivation promoted soil subsidence in EAA and reduced the soil depth to bedrock limestone. The incorporation of limestone into surface soil has significantly increased soil pH which in turns causes greater fixation of P fertilizer into unavailable forms for plant growth.

The incorporation of limestone into surface soils enhanced P sequestration in inorganic pools for soils supporting sugarcane production. Continuation of conventional crop management practices will further increase soil pH, leading to greater retention of P fertilizer in inorganic pools and a decrease in the proportion of P fertilizer remaining in plant-available form. In turn, higher P fertilization rates will be required to satisfy crop nutrient requirements with increasing continuation of conventional cropping practices.

While most of the inorganic P pools are unavailable to sugarcane, the direct conversion of sugarcane soils to wetlands may facilitate P release with unwanted environmental effects. Reclamation of sugarcane fields for environment uses would benefit by an intermediate step to allow for a short duration of seasonal flooding allowing for P conversion from inorganic to organic forms. Prolonged flooding of organic soils previously used for intensive agriculture is not recommended.

For more Information

Castillo, M.S., and A.L. Wright. 2008. Soil phosphorus pools for Histosols under sugarcane and pasture in the Everglades, USA. Geoderma 145:130-135.

Castillo, M.S., and A.L. Wright. 2008. Microbial activity and phosphorus availability in a subtropical soil under different land uses. World J. Agric. Sci. 4:314-320.

Table 1. Physical properties and nutrient concentrations of sugarcane and uncultivated soils in the Everglades Agricultural Area. Significant differences between land uses were noted by * ($P < 0.05$) and not significant (NS).

Soil Property	Units	Sugarcane	Uncultivated Soil	P < 0.05
pH		6.8	5.3	*
Water-holding capacity	%	142	196	*
Bulk density	g cm^{-3}	0.41	0.44	NS
Total organic carbon	ppthou	440	435	NS
Total nitrogen	ppthou	32	30	NS
Carbon:nitrogen ratio		14	15	NS
Available ammonium	ppm	158	246	*
Available nitrate	ppm	54	162	*
Available P	ppm	1.3	3.9	*
Total P	ppm	1227	959	*
Total inorganic P	ppm	650	178	*
Carbon:phosphorus ratio		360	460	*