Baseline Soil Characterization for Compartment B in Stormwater Treatment Area 2 and Compartment C in Stormwater Treatment Area 5/6

October 23, 2019

Prepared by

Manuel F. Zamorano

Tracey Piccone

Stephen Colon

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASUREMENT

°C	degrees Celsius
ac	acre, acres
AFDW	ash free dry weight
BD	bulk density
CaMg-Pi	calcium- and magnesium-bound inorganic phosphorus
cm	centimeter, centimeters
CNS	carbon-nitrogen-sulfur
EAV	emergent aquatic vegetation
EFA	Everglades Forever Act
EPA	Everglades Protection Area
FeAl-Pi	iron- and aluminum-bound inorganic phosphorus
ft	foot, feet
g cm^{-3}, g/cm^3	grams per cubic centimeter
g kg^{-1}, g/kg	grams per kilogram
g m^{-2}, g/m^2	grams per square meter
g P m^{-2}, g P/m^2	grams phosphorus per square meter
GIS	geographic information system
GPS	Global Positioning System
HCl	hydrochloric acid
KCl	potassium chloride
Li-P	labile inorganic phosphorus
m	meter, meters
mg kg^{-1}, mg/kg	milligram per kilogram
NaOH	sodium hydroxide
P	phosphorus
Pi	inorganic phosphorus fraction
Po	organic phosphorus fraction
RBF	radial basis function
RWMA	Rotenberger Wildlife Management Area
SAV	submerged aquatic vegetation
SFWMD	South Florida Water Management District
SPS	soil phosphorus storage
STA	stormwater treatment area
STA-1E	Stormwater Treatment Area 1 East
STA-1W	Stormwater Treatment Area 1 West
TC	total carbon
TCa	total calcium
TN	total nitrogen
TP	total phosphorus
WCA-2A	Water Conservation Area 2A

INTRODUCTION

The construction and operation of large freshwater treatment wetlands, known as the Everglades Stormwater Treatment Areas (STAs), are mandated by the Everglades Forever Act (EFA; Section 373.4592, Florida Statutes). These wetlands are an integral part of state and federal efforts to reduce total phosphorus (TP) concentration in surface water discharged into the Everglades Protection Area (EPA). The goal is to reduce the water TP concentrations within the Everglades ecosystem to low values, which will help to preserve the remaining Everglades ecosystem.

These constructed wetlands—STA-1 East (STA-1E), STA-1 West (STA-1W), STA-2, STA-3/4, and STA-5/6—are located south of Lake Okeechobee and are designed to reduce TP concentrations in surface water runoff before discharging to the EPA (**Figure 1**). The STAs are operated by the South Florida Water Management District (SFWMD). The total area of the STAs, including infrastructure components, is roughly 68,000 acres (ac), with 57,000 ac of treatment area presently permitted to operate including the expansions of STA-2 (Compartment B) and STA-5/6 (Compartment C).
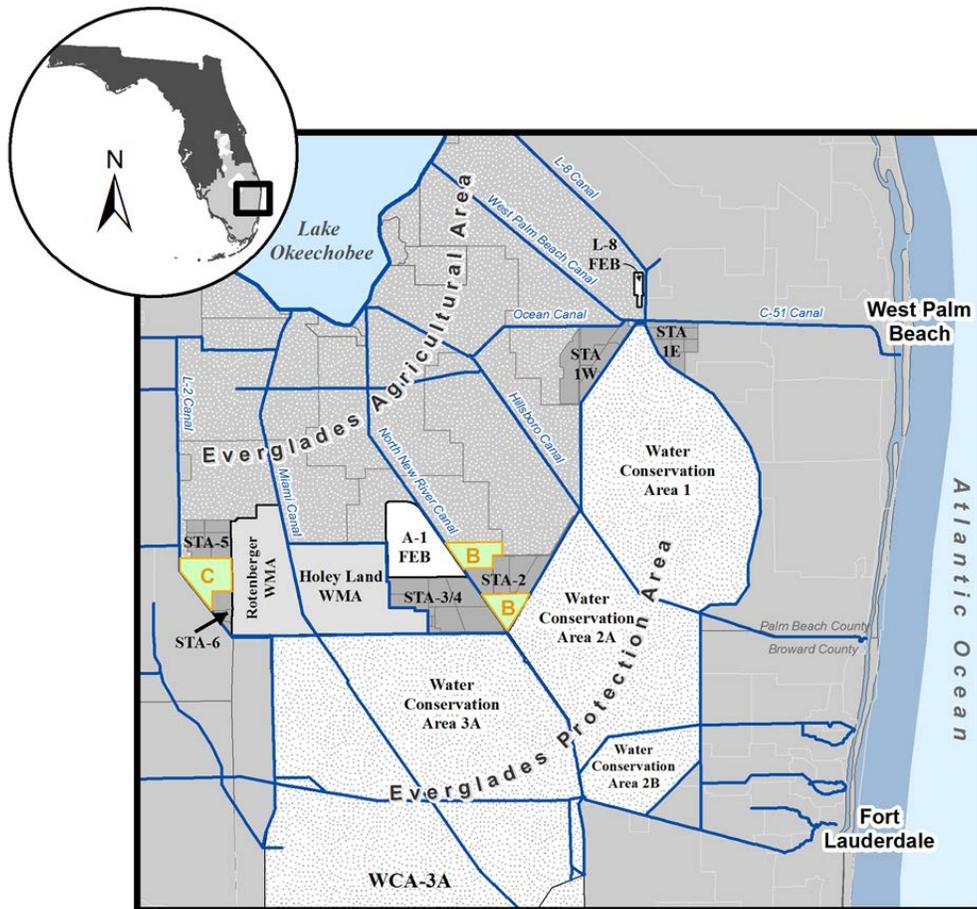
Figure 1. Map of Everglades STAs including Compartments B and C.

The STAs are constructed primarily on former agricultural lands and retain nutrients through plant and microbial uptake, particulate settling, chemical sorption, and ultimately accretion of the plant and microbial biomass into the soils (Kadlec 1999). The conversion process from farmland to constructed wetland typically involves flooding these areas to create conditions suitable for wetland vegetation growth. The initial flooding can potentially result in changes in phosphorus (P) speciation and concentration in the soils, which can cause fluxes of P into the water column, a condition that can last several weeks after flooding (Newman and Pietro 2001, Pant and Reddy 2001, White et al. 2004).

P in soils is found in both inorganic and organic forms, with prevailing form being refractory organic P in wetlands (Reddy et al. 1998). The proportion of the different P pools varies as a result of the previous soil management practices for each area. Labile forms of P, including labile inorganic and organic P, are especially important in treatment wetlands as these forms are the most readily available for plant uptake. Other P forms and/or fractions also play important roles in soil P storage. Some forms of inorganic P extracted with hydrochloric acid (HCl) and sodium hydroxide (NaOH) from calcium- and iron-/aluminum-bound P, respectively, are susceptible to changing environmental conditions (i.e., drying and rewetting of soils, redox, pH). Po requires more complex processes involving biological processing by microbes before P is assimilated or released back into the system (White et al. 2004, Bostrom et al. 1988). For newly created STAs, soil constituents are measured to determine the amount of labile and non-labile forms of P. These data establish baseline conditions, to evaluate P changes over time, and to compare P content and forms of different STAs and cells within STAs.

This technical publication summarizes the soil characterization results from the baseline soil sampling conducted in 2010 for the acreage associated with the expansions of STA-2 (Compartment B) and STA-5/6 (Compartment C) (**Figure 1**). The specific objectives of the study were to do the following:

1. Measure the spatial distribution of soil physicochemical properties of the soils.

2. Identify relative proportions of labile and non-labile pools of P in soils.

3. Estimate P storage capacity of Compartments B and C and compare this to baseline and current soil characteristics of existing STA cells.

MATERIAL AND METHODS

SITE DESCRIPTION

STA-2 is in Palm Beach County between the North New River Canal to the west and Water Conservation Area 2A (WCA-2A) to the east. STA-2 currently encompass an area of approximately 15,900 ac including the addition of nearly 7,100 ac referred to as Compartment B (**Figure 1**). STA-2 consists of eight treatment cells configured in five flow-ways (Piccone et al. 2014). STA-2 Flow-ways 1 to 3 started operation in 1999 (Pietro 2012), with the remaining cells in Compartment B (Flow-ways 4 and 5) starting operation in late 2012 (Flow-way 4) and mid-2013 (Flow-way 5), (Chimney 2014).

STA-5/6 is in Hendry County and is situated adjacent to the west side of the Rotenberger Wildlife Management Area (RWMA). STA-5/6 consists of approximately 15,900 ac including the addition of nearly 8,750 ac referred to as Compartment C (**Figure 1**). STA-5/6 consists of fourteen treatment cells configured in eight flow-ways (Piccone et al. 2014). STA-5 and STA-6 started operation in 1998 and 1999, respectively. With the addition of Compartment C in 2012, these STAs were combined to become STA-5/6 (Pietro 2012). Prior to STA construction, most of the areas included in Compartments B and C were drained and used for agricultural production.

SOIL SAMPLING AND ANALYSES

Sample sites were selected using the geographic information system (GIS) simple random sampling tool for each cell in which 20% of the random sample points selected were derived from the previously established 1,330-feet (ft) x 1,330 ft STA georeferenced sampling grid. All sampled sites (see the Appendix) were located using a handheld global positioning system (GPS) device. In August 2010, a total of 63 stations were sampled consisting of 38 stations in Compartment B and 25 stations in Compartment C (**Figures 2** and **3**). The sample site was within a 20-meter (m) radius of the sampling station. Within this radius, the sample site was chosen: (1) in an undisturbed location (i.e., avoiding dirt roads and other manmade infrastructure) and (2) away from large, woody vegetation.

Soil samples were collected by driving a 10-cm diameter stainless steel corer into the soil profile. While driving in the core, the sampler used a serrated knife to cut around the outside perimeter of the corer to reduce soil compaction. Soil cores were extruded in the field and the top 0- to 10-cm layer was collected. Soils were qualitatively described using the Munsell soil color system, which evaluates hue and chroma (Munsell Color 2000). This was followed by evaluating the soil texture roughness or smoothness to estimate the presence of sand, silt, and clay in the soil (Thien 1979). Vegetation, roots, rocks, and shells were removed from the samples before they were placed in waterproof plastic bags. The bags were then put in an ice cooler for transport to the laboratory where they were stored in a refrigerator and kept at a temperature of approximately 4 degrees Celsius (°C) prior to analysis.

Soil samples were analyzed for TP using the dry ashing method (Andersen 1976) followed by a colorimetric procedure following Standard Method 4500-P F. Automated Ascorbic Acid Reduction Method (USEPA 2017). Total nitrogen (TN) and total carbon (TC) were analyzed with a Carlo-Erba NA 1500 series carbon–sulfur–nitrogen (CNS) analyzer. Total calcium (TCa) extracted with an acid digest and analyzed using inductively coupled argon plasma emission spectrometry using Method 200.7: Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry (USEPA 1994). Bulk density (BD) was determined using the volume and dry weight of each sample (Fox and Page-Hanify 1959). Ash free dry weight (AFDW) was calculated after ignition at 550°C.

Soils were also analyzed for various organic and inorganic P fractions using the sequential P fractionation scheme developed for histosols (Reddy et al., 1998). The labile inorganic P (Li-P; potassium chloride [KCl] extraction), iron- and aluminum-bound inorganic P (FeAl-Pi; NaOH-Pi extraction), and the calcium- and magnesium-bound inorganic P (CaMg-Pi; HCl-Pi extraction) fractions were determined. The organic P fraction (Po) was determined as the difference between the NaOH-TP extractable and the NaOH-Pi extraction associated with the FeAl-Pi. Residual P was calculated by the difference between TP and the sum of the extractable fractions listed above. All samples were processed and analyzed by DB Laboratories in Rockledge, Florida.

The estimated total soil phosphorus storage (SPS) was calculated per unit area for the upper 10 cm of soil with the following equation:

$$SPS\left(\frac{g}{m^2}\right) = \frac{TP\left(\frac{mg}{kg}\right) x \, BD\left(\frac{g}{cm^3}\right) x \, d\,(cm)}{100}$$

where SPS is the amount of P stored in the surface soil layer in and expressed in grams per square meter (g m^{-2} or g/m^2), TP is the TP content of the soil in milligrams per kilogram (mg/kg or mg kg^{-1}), BD is the soil bulk density in grams per cubic centimeters (g/cm^3 or g cm^{-3}), and d is the soil sampling depth (cm).
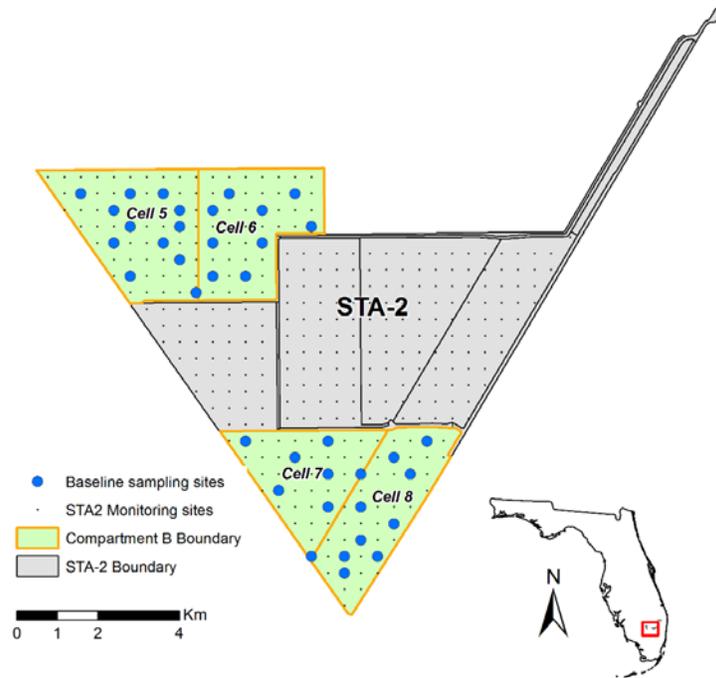
Figure 2. Map of STA-2 showing Compartment B Cells and internal baseline soil sampling sites.
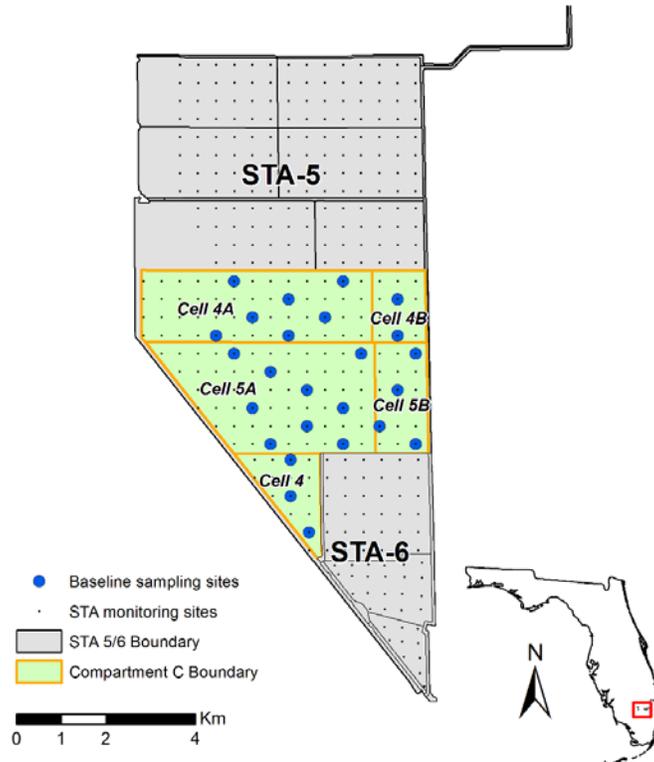
Figure 3. Map of STA-5/6 showing Compartment C Cells and internal baseline soil sampling sites.

DATA ANALYSES

Summary statistics were calculated for soil physicochemical parameters within Compartments B and C. The estimated total SPS for compartment B and C is presented in relation to baseline and current soil characteristics of existing STA cells to include samples collected from 2003 to 2010. Pearson's correlation coefficients were determined to evaluate relationships among soil properties. All statistical analyses were performed with Statistical Analysis Systems software Version 9.1 (SAS Institute Inc. 2002).

Spatial analyses of soil properties (TP, TN, TC, TCa, BD, and AFDW) were performed using the Arc GIS Release 9 spatial analyst extension (ESRI 2010). The radial basis function (RBF) or spline with tension function was used to estimate or interpolate values in unsampled areas by using reported measured values. This interpolation method employs mathematical functions to produce a smooth curvature surface that passes through each of the measured points. Subsequently, interpolated classed maps were created to show the spatial variability of soil characteristics in each cell in Compartments B and C.

RESULTS

SOIL CHARACTERISTICS

Based on Munsell Color System[1] (Munsell Color Company, Inc. 2000) soil characterization, most of the soils in Compartment B consisted of hydric organic soils (10YR 2.5/1) characterized by loams with traces of clay. In Compartment C, soil types were slightly more mineral (10YR 2.5/1 and 7.5YR 2.5/1) and included a mixture of sandy clay loam soils. However, soil physicochemical characteristics in Compartment B were different from Compartment C (**Tables 1** and **2**). The mainly organic soils in Compartment B exhibited a high percent of AFDW values (mean ± standard deviation; 74.8 ± 12%) and low BD (0.3 ± 0.08 g cm^{-3}), while the more mineral soils in Compartment C showed low percentages of AFDW (18.9 ± 19.2%) and higher BD values (1.0 ± 0.4 g cm^{-3}). Total P concentrations in Compartment B averaged 666 ± 150 mg kg^{-1}, approximately twice the average TP for Compartment C of 320 ± 251 mg kg^{-1}. Compartment B TCa values were higher than Compartment C with mean concentrations of 39.7 ± 8.8 g kg^{-1} and 7.2 ± 6.7 g kg^{-1}, respectively. TC and TN concentrations were also higher in Compartment B than Compartment C. Mean TC and TN in Compartment B were 415 ± 71 g kg^{-1} and 26.4 ± 5.7 g kg^{-1}; Compartment C values averaged 101 ± 101 g kg^{-1} and 7.6 ± 7.3 g kg^{-1} correspondingly, which exhibited a large variability between cells. There were no consistent patterns in the spatial distribution of analyzed soil constituents. However, slightly higher soil TP concentrations were found in Compartment B Cells 5 and 7 compared to the other cells (**Figures 4** through **9**).

---

[1] The Munsell Color System uses three elements of color—hue, value, and chroma—to make up a color notation. The notation is recorded in the form: hue, value/chroma. The Munsell Color System is based on five principal hues—red (R), yellow (Y), green (G), blue (B), and purple (P)—and five intermediate hues— yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP)—representing midpoints between each pair of principal hues. Value indicates the degree of lightness or darkness of a color in relation to a neutral gray scale, which extends from pure black (0/) to pure white (10/) with gray (5/) being about halfway between black and white. Chroma is the relative purity or strength of the spectral color; it indicates the degree of saturation of neutral gray by the spectral color. The scales of chroma for soils extend from /0 for neutral colors to a chroma of /8 as the strongest expression of color used for soils. For example, 10YR 2.5/1 indicates the soil is dark brown (yellow-red) within the 10-hue color system with a weak strength of the yellow-red hue. For more information, see https://munsell.com/about-munsell-color/how-color-notation-works/.

Table 1. STA-2 Compartment B (mean ± standard deviation)
soil characterization data for the 0- to 10-cm depth layer.

Parameter	Unit	Cell 5	Cell 6	Cell 7	Cell 8	All Cells
AFDW	%	67.7 ± 14.5	78.5 ± 12.5	72.6 ± 8.2	82.6 ± 1.5	74.8 ± 12
BD	g cm^{-3}	0.4 ± 0.1	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.1
TC	g kg^{-1}	371 ± 87	439 ± 704	403 ± 442	462 ± 15	415 ± 71
TCa	g kg^{-1}	40.2 ± 11.7	39 ± 8.7	41.9 ± 9.7	38 ± 2.7	39.7 ± 8.8
TN	g kg^{-1}	24 ± 4.9	26.5 ± 4	25.5 ± 2.8	30.2 ± 8.4	26.4 ± 5.7
TP	mg kg^{-1}	714 ± 206	626 ± 125	724 ± 90	595 ± 96	667 ± 150
Sample Size		12	9	8	9	38

Note: g kg^{-1} – grams per kilogram.

Table 2. STA-5/6 Compartment C (mean ± standard deviation)
soil characterization data for the 0- to 10-cm depth layer.

Parameter	Unit	Cell 4A	Cell 4B	Cell 5A	Cell 5B	Cell 4	All Cells
AFDW	%	14.5 ± 12.3	17.3 ± 14.8	11.7 ± 17.4	46.7 ± 21.0	13.6 ± 10.8	19 ± 19
BD	g cm^{-3}	1.0 ± 0.4	0.8 ± 0.4	1.1 ± 0.3	0.5 ± 0.1	1. ± 0.4	1 ± 0.4
TC	g kg^{-1}	82.1. ± 62.9	85.9 ± 69.4	61.5 ± 91.5	246 ± 113	83.5 ± 67	101.4 ± 101
TCa	g kg^{-1}	6.1 ± 5.4	9.3 ± 2.3	4.2 ± 6.3	15.8 ± 7.7	6.1 ± 2.4	7.2 ± 6.7
TN	g kg^{-1}	6,310 ± 4,638	6,140 ± 5,077	4,666 ± 6,657	18,225 ± 8,181	6,476 ± 5,129	7.6 ± 7.4
TP	mg kg^{-1}	370 ± 288	258 ± 139	230 ± 281	534± 129	235 ± 76	321 ± 251
Sample Size		7	2	9	4	3	25

Note: g kg^{-1} – grams per kilogram.

Compartment B   **Compartment C**
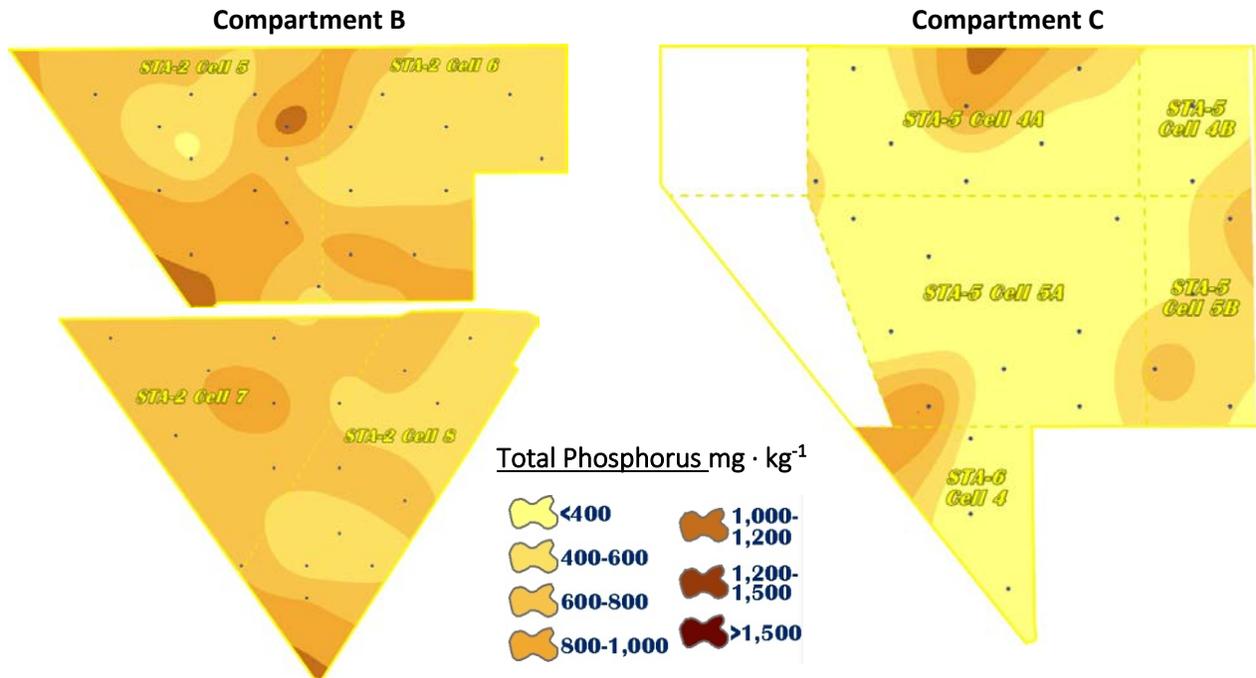
Figure 4. Spatial distribution of TP in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.

Compartment B   **Compartment C**
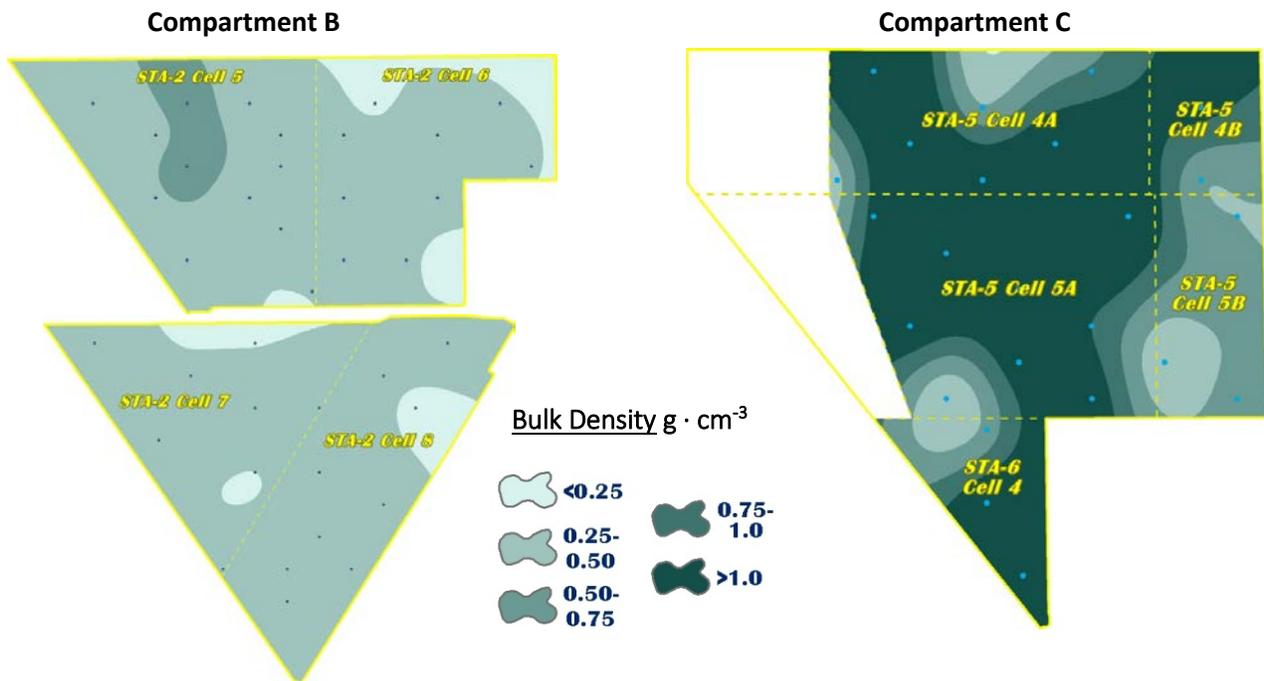
Figure 5. Spatial distribution of BD in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.

Compartment B   **Compartment C**
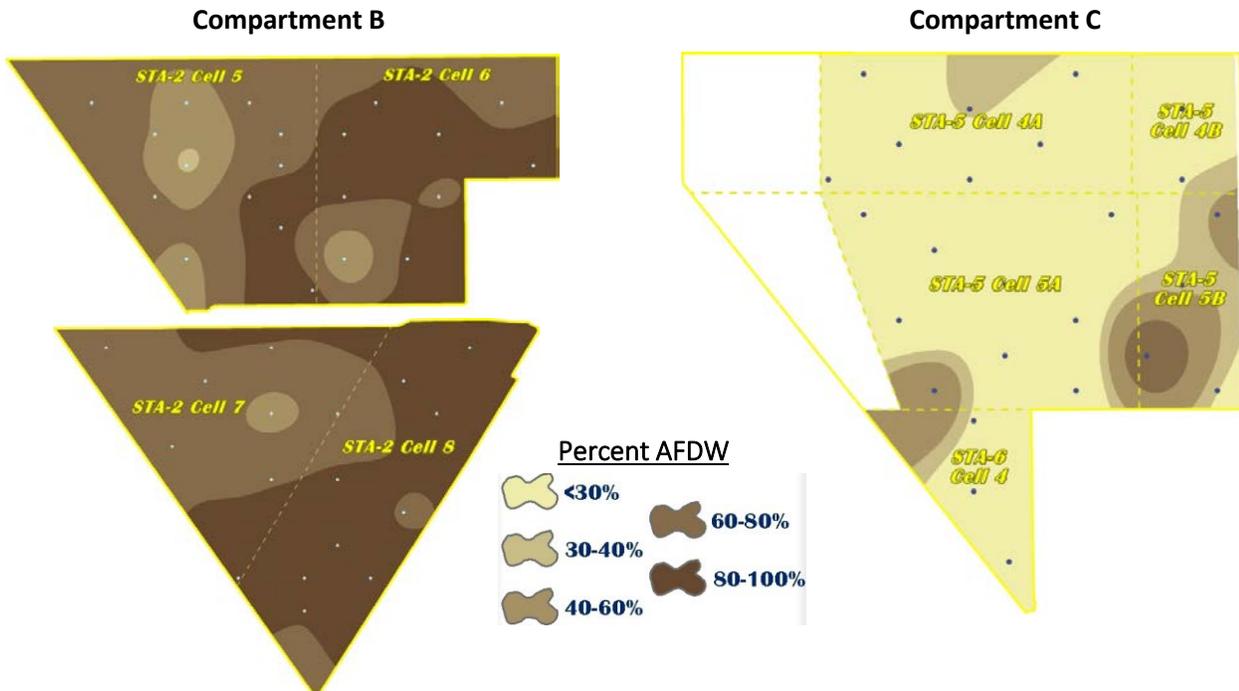
Figure 6. Spatial distribution of AFDW in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.

Compartment B   **Compartment C**
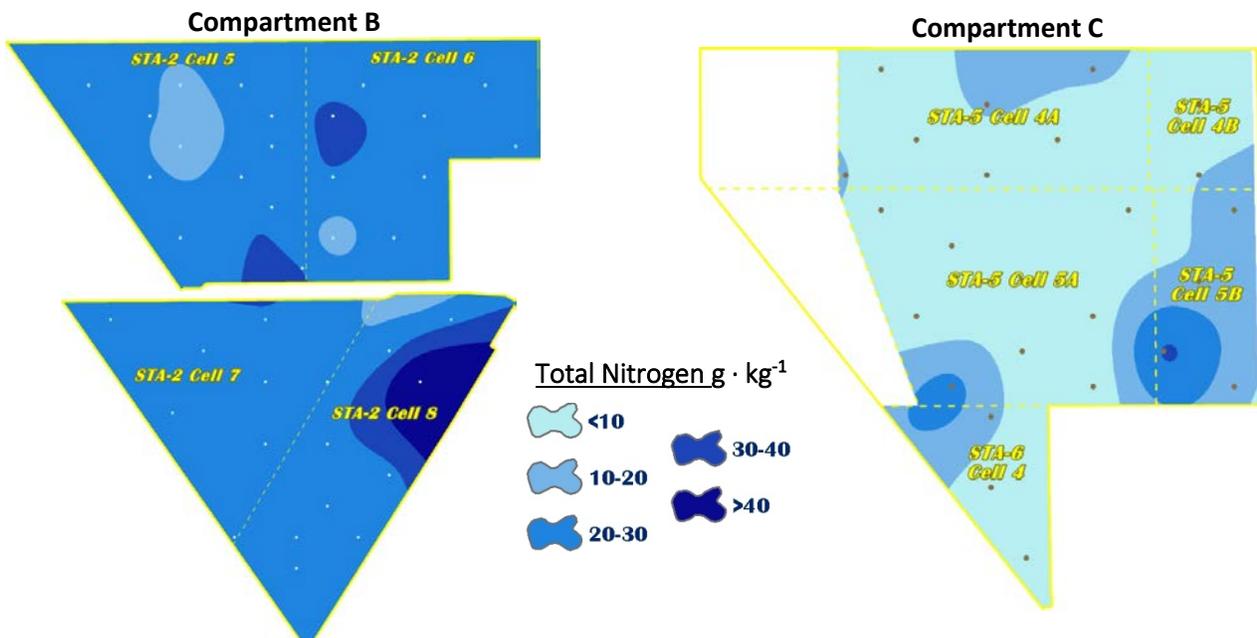
Figure 7. Spatial distribution of TN in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.

Baseline Soil Characterization for Compartment B in STA-2 and Compartment C in STA-5/6
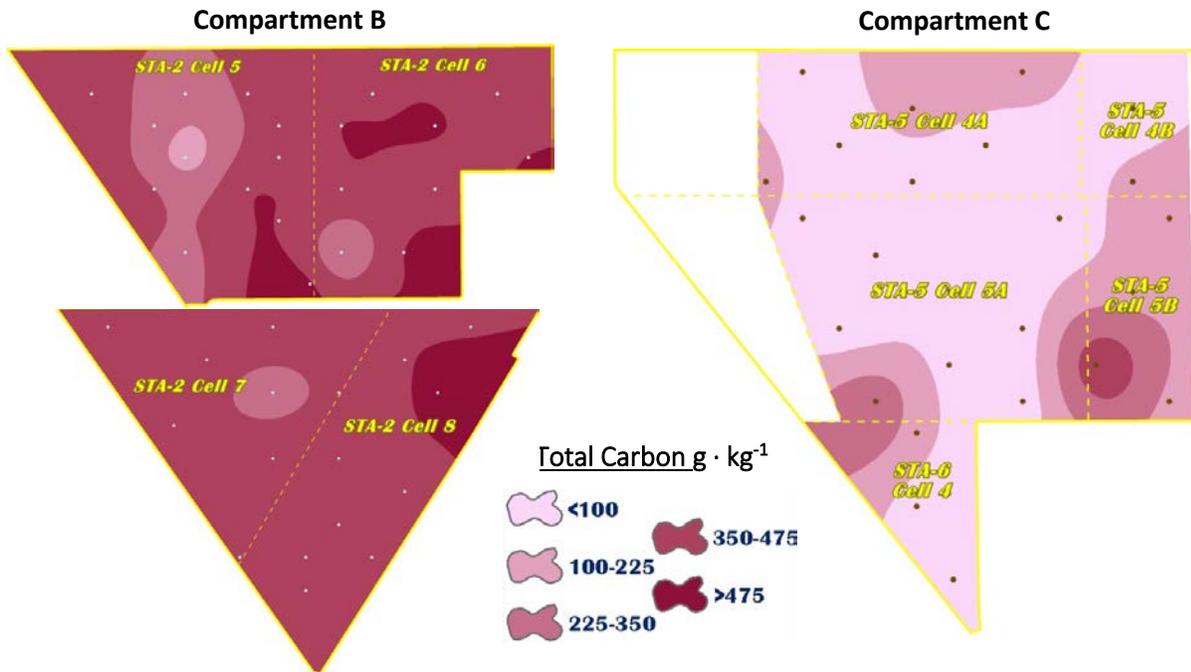
Figure 8. Spatial distribution of TC in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.
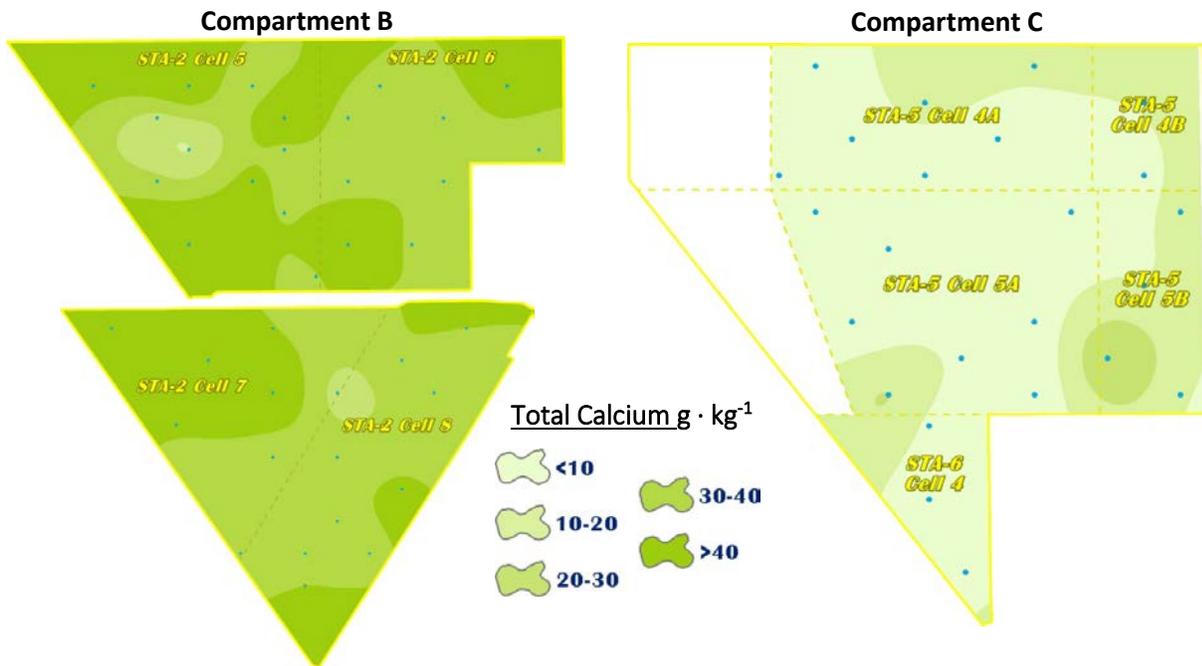
Figure 9. Spatial distribution of TCa in the upper 10-cm soil layer of Compartments B and C in 2010. Sampling locations are designated with dots on the map.

13

SOIL PHOSPHORUS STORAGE

Comparison of soil physicochemical characteristics between the cells in Compartments B and C and the original treatment cells in STA-2, STA-5, and STA-6 demonstrates differences that can be attributed to the 10 years of operation of these STAs. The original STA cells were subjected to nutrient loads associated with runoff in addition to any legacy soil P. Therefore, temporal changes in P storage serve as an indication of the relative stability of the accreted material compared to startup conditions. SPS in Compartment B was considerably higher than values recorded in 2009 for soils in Cells 1 and 2 in STA-2, and slightly higher or similar to values recorded in Cells 3 and 4 (**Table 3**). In addition, the amount of P stored in Compartment B soils was approximately two to three times higher than values recorded nearly three years after STA-2 became operational in 1999, an indication of the highly P enriched soils in Compartment B. However, an important distinction exists in SPS values between emergent aquatic vegetation (EAV)-dominated cells (Cells 1 and 2) and SAV cells (Cells 3 and 4) in STA-2, with submerged aquatic vegetation (SAV) soils having higher SPS values than soils from EAV cells. Higher SPS values in the SAV cells are relatively similar to values observed in the Compartment B soils.

Table 3. STA-2 and Compartment B mean ± standard deviation SPS in the upper 10-cm soil layer.

STA-2 Cell	Mean ± Standard Deviation SPS (g P m^{-2})			
	2003	2007	2009	2010
Cell 1	6.7 ± 0.7	6.3 ± 1.8	7.4 ± 3.6	--
Cell 2	10.7 ± 4.3	11.4 ± 4.5	10.3 ± 4.1	--
Cell 3	12.8 ± 14.1	12.3 ± 5.8	17.2 ± 18.4	--
Cell 4	--	18.3 ± 11.3	16.9 ± 6.9	--
Cell 5 *	--	--	--	23.8 ± 6.8
Cell 6 *	--	--	--	19.2 ± 5.9
Cell 7 *	--	--	--	20.6 ± 6.9
Cell 8 *	--	--	--	18.3 ± 6.1

An asterisk (*) indicates that the cell is in Compartment B.

A dash (--) indicates no sampling was conducted in the cell for the year.

In the Compartment C soils, SPS values ranged from 9.7 ± 2.8 grams of P per square meter (g P m^{-2}) to 44.3 ± 27.8 g P m^{-2}. This range is comparable to previously recorded values in STA-5 and STA-6 with no distinct differences between EAV and SAV cells (**Table 4**). However, the amount of P stored in these soils varied substantially among cells and between sampling sites within each cell. The variability among cells may be the result of unique P-enriched areas (hot spots) found within each cell, a condition that has been previously observed in STA soils during initial baseline soil characterizations.

Table 4. STA-5/6 and Compartment C mean ± standard deviation SPS in the upper 10-cm soil layer.

Cell	Mean ± Standard Deviation SPS (g P m⁻²)			
	2003	2007	2008	2010
STA-5				
Cell 1A	21.1 ± 14.7	21.83 ± 10	--	--
Cell 1B	17.4 ± 6.6	15.6 ± 3.4	--	--
Cell 2A	18.1 ± 6.2	33.6 ± 18.6	--	--
Cell 2B	16.2 ± 6.0	23.8 ± 24	--	--
Cell 3A	--	--	30.7 ± 14.4	--
Cell 3B	--	--	24.7 ± 10.2	--
Cell 4A *	--	--	--	26.4 ± 20.4
Cell 4B *	--	--	--	44.3 ± 27.8
Cell 5A *	--	--	--	29.6 ± 23.5
Cell 5B *	--	--	--	9.7 ± 2.8
STA-6				
Section 2	--	53.3 ± 18.4	--	--
Cell 3	15.6 ± 10.1	--	9.7 ± 1.9	--
Cell 4 *		--	--	41.6 ± 24.8
Cell 5	23.5 ± 11.4	--	21.7 ± 13.6	--

An asterisk (*) indicates that the cell is in Compartment B.

A dash (--) indicates no sampling was conducted in the cell during the year.

SOIL PHOSPHORUS FRACTIONATION

Approximately 70 to 80% of the TP in Compartments B and C soils were organic P and residual P forms, which normally consists of highly refractory Po (White et al. 2004; **Figures 10** and **11**). These forms are relatively stable and not readily released into the water column and/or easily available for rooted plant uptake (Reddy et al. 1998). The relative distribution of Po and residual P appeared in different proportions for the two compartments. The KCL-extractable P associated with the labile Pi, which is the more available fraction for release and uptake by plants, accounted for less than 1% of the TP. Compartment B had higher P concentrations than Compartment C for most fractions, except for the FeAl-Pi (NaOH-Pi) associated fraction. The CaMg-Pi (HCl-Pi) fraction was considerably higher in Compartment B than in Compartment C. In general, the CaMg-Pi fraction in the soils is relatively stable given alkaline pH (> 7.0) conditions (White et al. 2006). The fraction associated with FeAl-Pi was slightly higher in the Compartment C soils than Compartment B soils, with higher concentrations in STA-5 Cells 4A and 5A (**Table 5**). Most P fractions were significantly correlated to each other (**Table 6**). A significant regression was found for HCL-extractable Pi and the TCa concentration for Compartments A and B combined ($r^2 = 0.57$, $p < 0.0001$; **Figure 12**). Additionally, a similar relationship was observed between TCa and TP ($r^2 = 0.43$, $p < 0.0001$; **Figure 13**), and TCa and the calculated residual P (not shown, $r^2 = 0.65$, $p < 0.0001$). These relationships suggest that Ca plays an important role in the sequestration, immobilization and storage of P in both Compartments B and C.
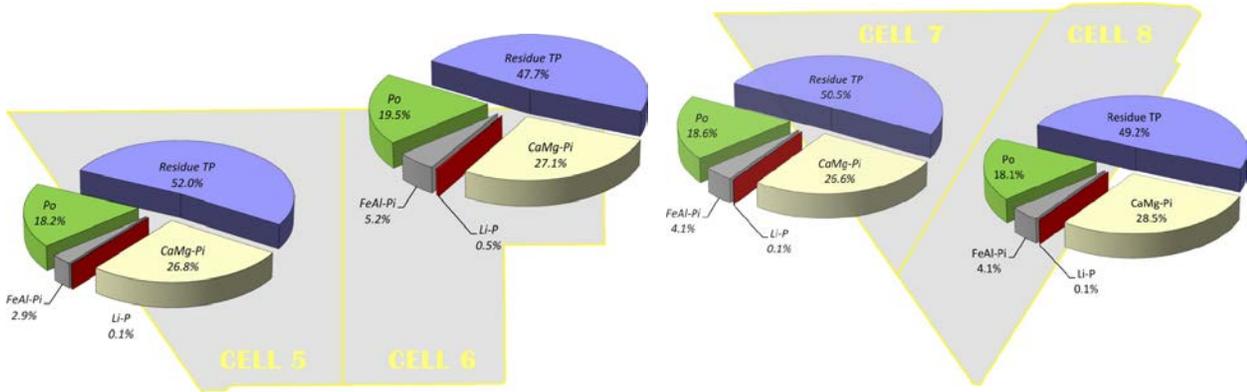
Figure 10. Relative distribution of Pi and Po in soils
from STA-2 cells in Compartment B for the 0- to 10-cm soil layer.
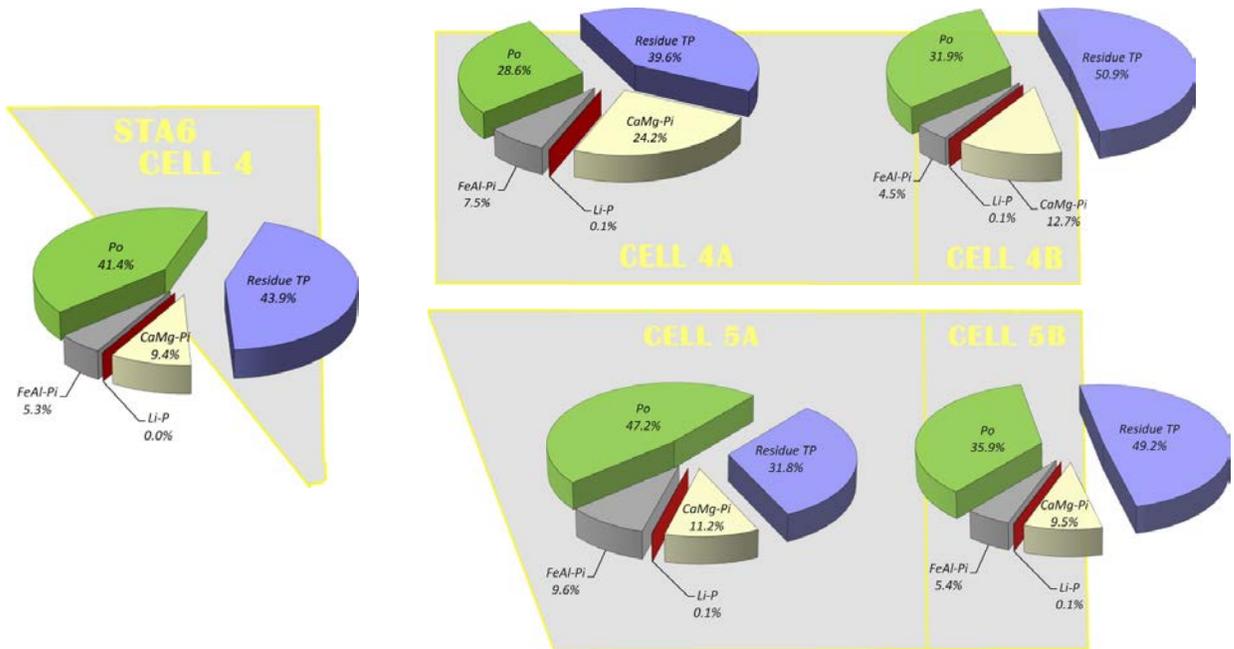
Figure 11. Relative distribution of Pi and Po in soils from STA-5
and STA-6 cells in Compartment C for the 0- to 10-cm soil layer.

Table 5. Mean ± standard deviation soil properties and concentration of the different Pi and Po from the 0- to 10-cm soil layer in Compartments B and C.

Cell	Mean ± Standard Deviation Soil Concentration (mg kg^{-1})					
	Po	Residue TP	CaMg-Pi	Li-P	FeAl-Pi	Porewater Po
Compartment B						
Cell 5	129.6 ± 35.2	371 ± 83.1	191.3 ± 102.4	0.8 ± 1.0	21 ± 8.0	0.3 ± 0.3
Cell 6	122.2 ± 27.7	298.1 ± 32.4	169.4 ± 72.5	2.9 ± 3.7	32.3± 16.0	1.2 ± 1.8
Cell 7	134.8 ± 21.2	364.5 ± 81.8	192.2 ± 79.9	0.6 ± 0.3	29.8 ± 8.0	0.3± 0.2
Cell 8	107.8 ± 10.6	292.7 ± 127.3	169.3 ± 72.5	0.3 ± 0.1	24.3 ± 6.3	0.2 ± 0.1
Compartment C						
Cell 4A	105.7 ± 80.5	146.3 ± 143	89.3 ± 108.7	0.4± 0.5	27.7 ± 13.6	0.2 ± 0.4
Cell 4B	85.1 ± 65.9	136 ± 59.3	33.9 ± 5.1	0.2 ± 0.0	11.9 ± 4.8	0.15 ± 0.2
Cell 5A	110.8 ± 142.1	74.5 ± 122.7	26.3 ± 15	0.3 ± 0.3	22.6 ± 19.92	0.1 ± 0.2
Cell 5B	187.4 ± 61.5	256.7 ± 95.4	49.4 ± 17	0.3 ± 0.2	28.3 ± 9.9	0.2 ± 0.0
Cell 4	97.5 ± 64.1	103.3 ± 36.6	22.1 ± 20.5	0.1 ± 0.0	12.6 ± 3.2	0.0 ± 0.0

Table 6. Correlations factors (r) between P fractions for Compartments B and C. Significant correlations at $p < 0.05$ are italicized.

	CaMg-Pi	Li-P	FeAl-Pi	Po	Residue TP	TP	TCa
CaMg-Pi	*1.00*						
Li-P	*0.28*	*1.00*					
FeAl-Pi	*0.28*	0.23	*1.00*				
Po	0.11	0.12	*0.60*	*1.00*			
Residue TP	*0.61*	0.22	*0.34*	*0.44*	*1.00*		
TP	*0.56*	*0.26*	0.20	0.11	*0.55*	*1.00*	
TCa	*0.76*	0.23	*0.31*	0.26	*0.81*	*0.65*	*1.00*
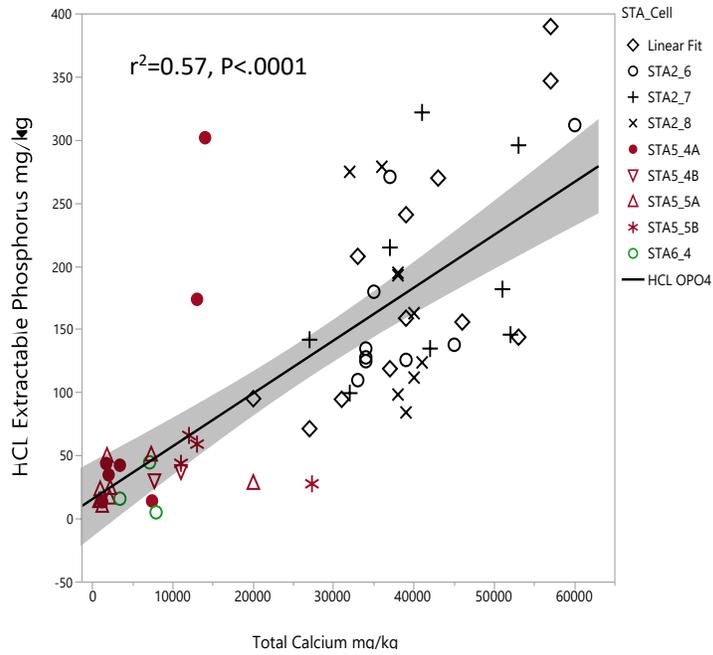
Figure 12. Relationship between HCL-extractable P and TCa in soils from Compartments B and C.
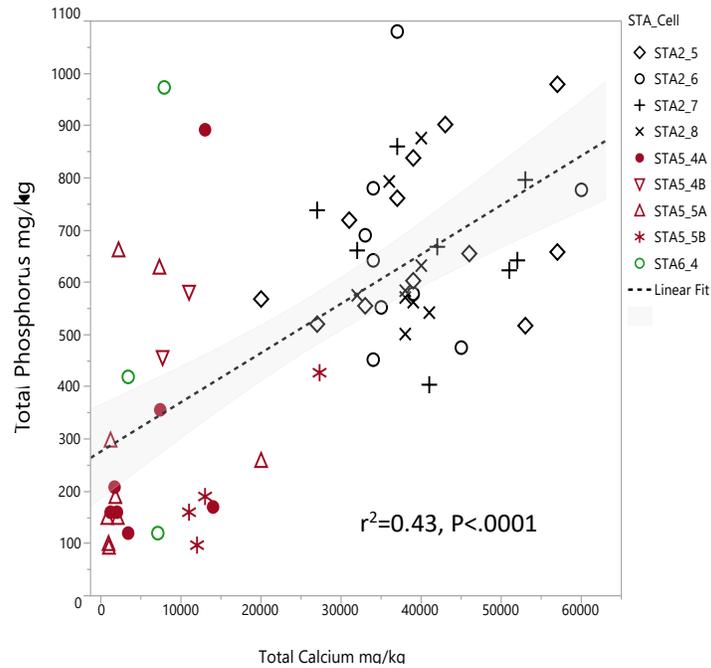
Figure 13. Relationship between TP and TCa in soils from Compartments B and C.

CONCLUSION

The baseline soils in Compartments B and C had marked differences in P concentrations and P fractions. On average, soil TP was nearly twice as high in Compartment B than Compartment C. Compartment B soils had higher TCa concentrations than Compartment C soils. A significant correlation between soil TP, as well as other P fractions, and TCa suggests that calcium plays an important role in P dynamics in the STAs. Similarly, the percent of AFDW and TC concentrations in the soils differentiated the highly organic nature of the soils in Compartment B compared to the slightly more mineral and sandy form found in Compartment C. Furthermore, low BD values in Compartment B soils suggests a less consolidated and less cohesive soil type than Compartment C. Therefore, total P mass is greater on a volumetric basis in Compartment C than B. Both Compartments B and C soils had considerably high variability in the spatial distribution of soil P, suggesting the presence of P-enriched hot spots within each cell. Soils are an important component in the STAs since they provide long-term storage primarily for P and other nutrients. Therefore, physicochemical baseline soil characterizations are important evaluations of startup conditions in the STAs. Once STAs are fully operational and undergo flooding, nutrients stored in soils can potentially be released into the water column over time. Finally, the baseline soil characterization of these systems should be followed by further consecutive sampling and evaluation of conditions to gain a better understanding of changes in the systems that may affect their capacity to retain nutrients over time.

LITERATURE CITED

Andersen, J., 1976. An ignition method for determination of total phosphorus in lake sediments. *Water Research* 10:329-331.

Chimney, M. 2014. Chapter 5B: Performance and Operation of the Everglades Stormwater Treatment Areas. In: *2014 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

ESRI 2010. *ArcGIS Desktop: Release 9*. Environmental Systems Research Institute, Redlands, CA.

Fox, W.E., and D.S. Page-Hanify. 1959. A method of determining bulk density of soil. *Soil Science* 88:168-171.

Kadlec, R.H. 1999. The limits of phosphorus removal in wetlands. *Wetlands Ecololgy and Management* 7:165-175.

Munsell Color Company. 2000. *Munsell Soil Color Charts, 2000 Edition*. Munsell Color Co Inc., Baltimore, MD.

Newman, S., and K. Pietro. 2001. Phosphorus storage and release in response to flooding: Implications for Everglades Stormwater Treatment Areas. *Ecological Engineering* 18:23-38.

Pant, H.K., and K.R. Reddy. 2001. Hydrologic influence on stability of organic phosphorus in wetland detritus. *Journal of Environmental Quality* 30:668-674.

Piccone, T., H.J. McBryan, H. Zhao, and Y. Yan. 2014. *2012 Updated Everglades Stormwater Treatment Area Average Ground Elevations, Stage-Area/Stage-Volume Relationships and Effective Treatment Area*. South Florida Water Management District, West Palm Beach, FL.

Pietro, K., 2012. *Synopsis of the Everglades Stormwater Treatment Areas, Water Year 1996–2012*. Technical Publication ASB-WQTT-12-001, South Florida Water Management District, West Palm Beach, FL.

Reddy, K.R., Y. Wang, W.F. DeBusk, M.M. Fisher, and S. Newman. 1998. Forms of soil phosphorus in selected hydrologic units of the Florida Everglades. *Soil Science Society of America Journal* 62:1134-1147.

SAS Institute, Inc. 2002. SAS, Version 9.1. Statistical Analysis Systems Institute, Inc., Cary, NC.

Thien, S.J. 1979. A flow diagram for teaching texture by-feel analysis. *Journal of Agronomic Education* 8:54-55.

USEPA, 1994. Method 200.7: Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry (Revision 4.4). In: R. Campisano, K. Hall, J. Griggs, S. Willison, S. Reimer, H. Mash, M. Magnuson, L. Boczek, and E. Rhodes, *Selected Analytical Methods for Environmental Remediation and Recovery.* EPA/600/R-17/356, United States Environmental Protection Agency, Cincinnati, OH.

USEPA. 2017. Standard Method 4500-P F. Automated Ascorbic Acid Reduction Method. In: *Standard Methods for the Examination of Water and Wastewater*, United States Environmental Protection Agency, Washington, DC.

White, J.R., K.R. Reddy, and M.Z. Moustafa. 2004. Influence of hydrology and vegetation on phosphorus retention in Everglades stormwater treatment wetlands. *Hydrological Processes* 18:343-355.

White, J.R., K.R. Reddy, and J.M. Newman. 2006. Hydrologic and vegetation effects on water column phosphorus in wetland mesocosms. *Soil Science Society of America Journal* 70:1242-1251.

APPENDIX

Sample site locations for soils collected in Compartments B and C during summer 2010.

Compartment	STA	Cell	Site	Latitude Decimal Degrees	Longitude Decimal Degrees
B	STA-2	5	E204	26.40862	-80.5755
B	STA-2	5	E195	26.41233	-80.5918
B	STA-2	5	E192	26.41596	-80.5796
B	STA-2	5	E182	26.41968	-80.5959
B	STA-2	5	E185	26.41964	-80.5836
B	STA-2	5	E176	26.42333	-80.5918
B	STA-2	5	E179	26.4233	-80.5796
B	STA-2	5	E167	26.42701	-80.5958
B	STA-2	5	E171	26.42697	-80.5795
B	STA-2	5	E156	26.4307	-80.604
B	STA-2	5	E159	26.43067	-80.5918
B	STA-2	5	E161	26.43065	-80.5836
B	STA-2	6	F241	26.41227	-80.5715
B	STA-2	6	F243	26.41225	-80.5633
B	STA-2	6	F233	26.41961	-80.5714
B	STA-2	6	F236	26.41957	-80.5592
B	STA-2	6	F232	26.4232	-80.547
B	STA-2	6	F219	26.42694	-80.5714
B	STA-2	6	F222	26.42691	-80.5592
B	STA-2	6	F213	26.4306	-80.5673
B	STA-2	6	F217	26.43055	-80.551
B	STA-2	7	G288	26.35352	-80.5472
B	STA-2	7	G283	26.36084	-80.5431
B	STA-2	7	G275	26.36455	-80.5553
B	STA-2	7	G271	26.36818	-80.5431
B	STA-2	7	G273	26.36815	-80.535
B	STA-2	7	G262	26.37187	-80.5512
B	STA-2	7	G250	26.37558	-80.5634
B	STA-2	7	G255	26.37551	-80.5431
B	STA-2	8	H325	26.34616	-80.5391
B	STA-2	8	H321	26.34983	-80.5391
B	STA-2	8	H323	26.3498	-80.531
B	STA-2	8	H317	26.35348	-80.535
B	STA-2	8	H314	26.35712	-80.5269

Compartment	STA	Cell	Site	Latitude Decimal Degrees	Longitude Decimal Degrees
B	STA-2	8	H307	26.36082	-80.535
B	STA-2	8	H299	26.36811	-80.5228
B	STA-2	8	H293	26.37179	-80.5268
B	STA-2	8	H290	26.37543	-80.5187
C	STA-5	4A	4A44	26.40548	-80.9292
C	STA-5	4A	4A48	26.40547	-80.9129
C	STA-5	4A	4A33	26.40914	-80.9211
C	STA-5	4A	4A37	26.40913	-80.9048
C	STA-5	4A	4A22	26.4128	-80.9129
C	STA-5	4A	4A6	26.41648	-80.9251
C	STA-5	4A	4A12	26.41646	-80.9007
C	STA-5	4B	4B11	26.40545	-80.8885
C	STA-5	4B	4B5	26.41279	-80.8885
C	STA-5	5A	5A55	26.38347	-80.917
C	STA-5	5A	5A59	26.38346	-80.9007
C	STA-5	5A	5A49	26.38713	-80.9089
C	STA-5	5A	5A37	26.3908	-80.9211
C	STA-5	5A	5A42	26.39079	-80.9007
C	STA-5	5A	5A30	26.39446	-80.9089
C	STA-5	5A	5A18	26.39814	-80.917
C	STA-5	5A	5A5	26.40181	-80.9252
C	STA-5	5A	5A12	26.40179	-80.8966
C	STA-5	5B	5B18	26.38344	-80.8844
C	STA-5	5B	5B13	26.38712	-80.8926
C	STA-5	5B	5B8	26.39445	-80.8885
C	STA-5	5B	5B3	26.40178	-80.8844
C	STA-6	4	C4_14	26.36564	-80.9084
C	STA-6	4	C4_10	26.37298	-80.9125
C	STA-6	4	C4_3	26.38032	-80.9125