Appendix 5C-3: Use of Soil Inversion to Control Phosphorus Flux

Manohardeep Josan, Bob Taylor, and Kevin Grace[1]

SUMMARY

The Stormwater Treatment Area 1 West (STA-1W) Expansion #1 project (STA-1WX1) is part of the Restoration Strategies Regional Water Quality Plan (SFWMD, 2012a) to assist existing STA-1W and STA-1E in achieving the Water Quality Based Effluent Limit (WQBEL) (SFWMD, 2012b). Soils in previously farmed regions have accumulated substantial amounts of phosphorus (P) from fertilizer application over time, and such soils have the potential to release P to the water column once submerged under water. STA-1WX1 is located west of STA-1W and is composed of three new cells: 6, 7, and 8. As part of the construction project, the top soil in Cell 7 and half of Cell 6 was inverted through deep tilling to bring the bottom soil layers to the surface to minimize the potential of copper contamination to future biota. While the copper remediation effort was not the focus of the work presented in this Appendix, it was leveraged to study the potential to reduce total P in the surface soils through the soil inversion process.

Prior to the Cell 6 and Cell 7 soil inversion effort, South Florida Water Management District (SFWMD) conducted a pilot study in a portion of Cell 7 of STA-1WX1 using deep tilling to bring the underlying peat and marl layers to the surface. The results of soil sampling indicated significantly lower surface soil total phosphorus (TP) and higher total calcium in the Cell 7 inverted soils relative to the soils before the inversion.

Following the soil inversion work in Cells 6 and 7, a follow-up study was conducted to examine the potential benefits of soil inversion to reduce P flux to the water column by burying P-enriched topsoil and bringing up P deficient and calcium (Ca)-enriched sub-soil to the surface. The evaluation was conducted using soil incubation, where surface water was exchanged every two weeks for a total of three 2-week cycles. Soil cores from the inverted marl areas (tilled soil with marl as the dominant surface layer) of Cells 6 and 7 released lower amounts of soluble reactive phosphorus (SRP) and TP throughout the three incubation cycles compared to untilled soils from Cell 6.

A soil profile survey of untilled areas of Cell 6 revealed the presence of peat and marl layers with an average thickness of 23 and 19 centimeters (cm), respectively. The marl layer had the least amount of TP (median = 147 mg/kg) and higher amounts of calcium (median = 194,164 mg/kg) as compared to the surface muck soil (median TP= 819 mg/kg and Ca = 48,875 mg/kg). These soil data suggested that conducting soil inversion in the remaining untilled half of Cell 6 would have the potential to reduce P flux to the water column upon flooding through burial of higher TP topsoil and by increasing calcium concentrations at the surface layer. Based on these data and results, a decision was made to invert the soil in the remaining half of Cell 6 during the last phase of the STA-1WX1 construction.

[1] DB Environmental, Inc., Rockledge, Florida.

After the cells are flooded, the performance evaluation of the STA-1WX1 cells will be part of routine STA performance monitoring as well as the subject of another Science Plan study, i.e., the Use of Soil Amendments/Management to Control P Flux (SFWMD, 2018) to compare areas that received the soil inversion treatment (Cells 6 and 7) to areas that were not inverted (Cell 8).

For future potential soil inversion locations, it is recommended that a soil profile survey first be performed to determine the depth and thickness of the various soil type layers to guide the tilling efforts to achieve the maximum P flux reduction.

INTRODUCTION

The Everglades STAs have been constructed south of Lake Okeechobee and are being operated to reduce TP concentrations in surface water runoff from agricultural areas and other sources before discharging into the Everglades Protection Area. STA-1W, the oldest of the five Everglades STAs, consists of 2,648 hectares (ha) of effective treatment area and is currently undergoing expansion of an additional 1,740 ha. The expansion area for STA-1 West (STA-1WX1) is part of the Restoration Strategies Regional Water Quality Plan (SFWMD, 2012a) to assist existing STA-1W and STA-1E in achieving the Water Quality Based Effluent Limit (WQBEL) (SFWMD, 2012b). STA-1WX1 is located west of STA-1W and is composed of three new cells: 6, 7, and 8, which will provide additional treatment capacity for S-5A and C-51 West basin runoff. The expansion cells (**Figure 1**) will have submerged aquatic vegetation (SAV) as the predominate treatment vegetation type.

The surface soil within STA-1WX1 is predominantly muck, which is characteristic of agricultural soil in the Everglades Agricultural Area. Muck contains high levels of inorganic P, which has the potential to release high amounts of P into the water column upon flooding (Castillo and Wright 2008). Without some intervention in the expansion cells, P flux from soil to the water column has the potential to occur due to the concentration gradient between the porewater and the water column.

A potential management technique to reduce P flux from soil to the water column is soil inversion. This is a process of deep tilling the soil with special plows to bury the P enriched topsoil layer and bring subsurface lower P soil to the surface. It is a well-known agricultural practice to reduce annual herbicide usage by burying the weed seed bank and protecting the topsoil labile carbon from weathering (Gruber and Claupein 2009). In the STA-1WX1 area, the main goal of the soil inversion was for copper (Cu) remediation, i.e. burying the surficial soil layer that is enriched with Cu from decadal fungicidal applications, relative to the subsurface soil horizon (AECOM, 2018). The purpose of the soil Cu remediation was to minimize the bioaccumulation of Cu in the Florida Apple Snail (*Pomacea paludosa*) as determined by the Expanded Ecological Risk Assessment to the Everglades Snail Kite (*Rostrhamus sociabilis plumbeus*) and was approved by the U.S. Fish and Wildlife Service and the Florida Department of Environmental Protection (SFWMD 2015). Therefore, soil within approximately 800 ha of STA-1WX1, i.e., half of Cell 6 and all of Cell 7, were inverted for copper remediation purposes (**Figure 1**). The depth of soil over the caprock/limerock in Cell 8 is relatively shallow and, therefore, not conducive to soil inversion using the same equipment used for the STA-1WX1 work (AECOM, 2018).

In the areas of STA-1WX1 where soils were inverted (half of Cell 6 and all of Cell 7), peat or marl soil layers from as deep as 1 meter were brought to the surface (**Figure 2**). Generally, these sublayers have lower P content than the original surface layer, hence inversion is expected to reduce P flux to the water column. Additionally, bringing calcareous marl to the top layer may suppress P release from the soil to the water column upon flooding of the area (Sanchez and Porter 1994, Ivanoff et al. 1998, Dierberg et al. 2017). Soil inversion could significantly expedite the achievement of desired performance in the expansion cells. Therefore, soil inversion is being examined as a potentially cost-saving alternative to chemical amendments to improve STAs performance (Chimney 2015). The objective of this pilot study was to evaluate whether the proposed soil inversion being conducted for copper remediation would also be effective in reducing surface soil TP concentrations, and P flux (mainly soluble reactive P) from the sediment to the water column as compared to areas that were not inverted (untilled).

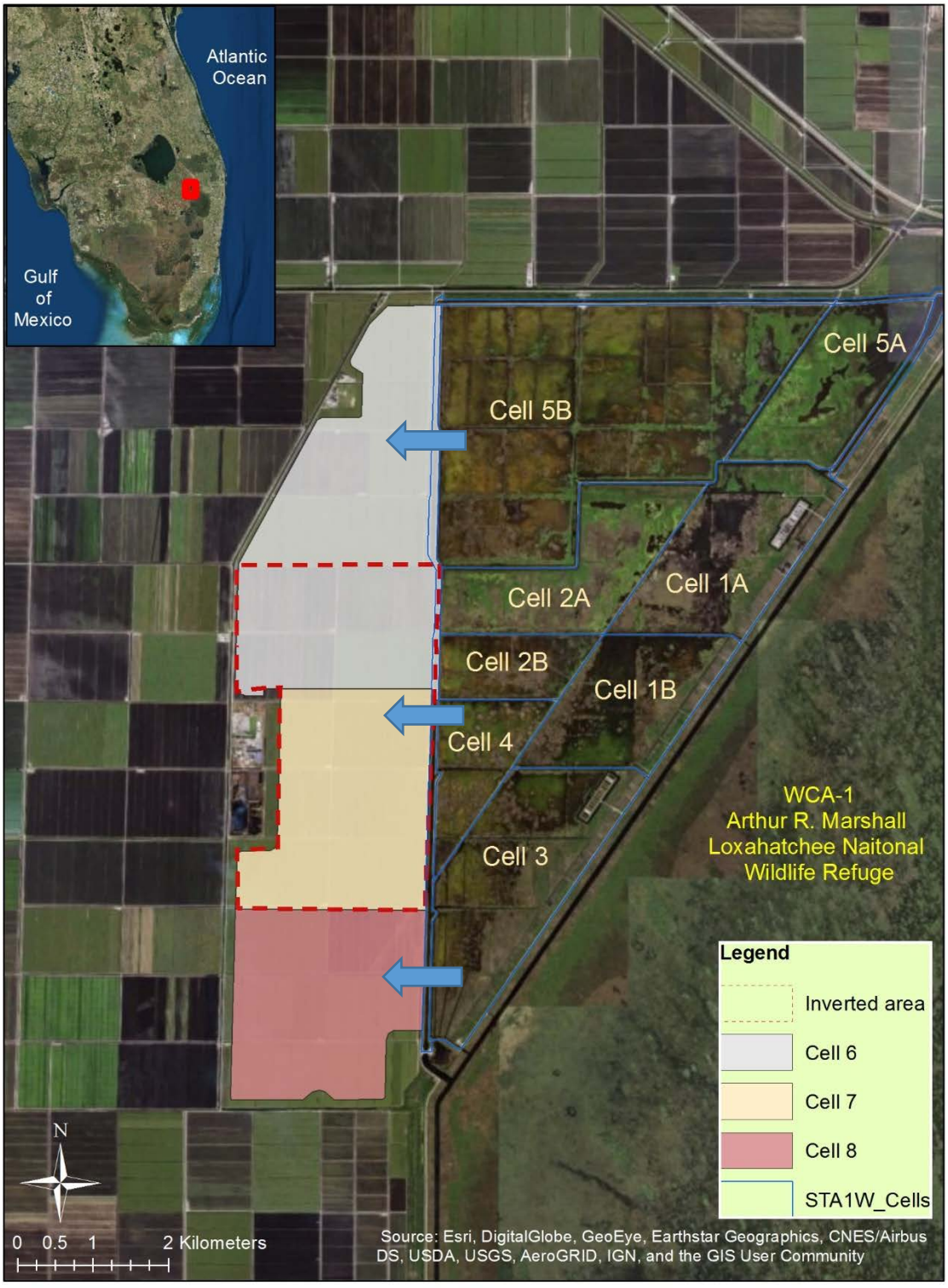

Figure 1. Map of STA-1W, which consists of 8 cells, and STA-1WX1 which includes 3 cells (6, 7, and 8). Each cell in STA-1WX1 is separated with levees and each will serve as a polishing cell for the existing STA flow-ways. The red dotted line depicts the areas where were inverted in Cells 6 and 7 for copper remediation purposes, whereas blue arrows show the direction of water flow.

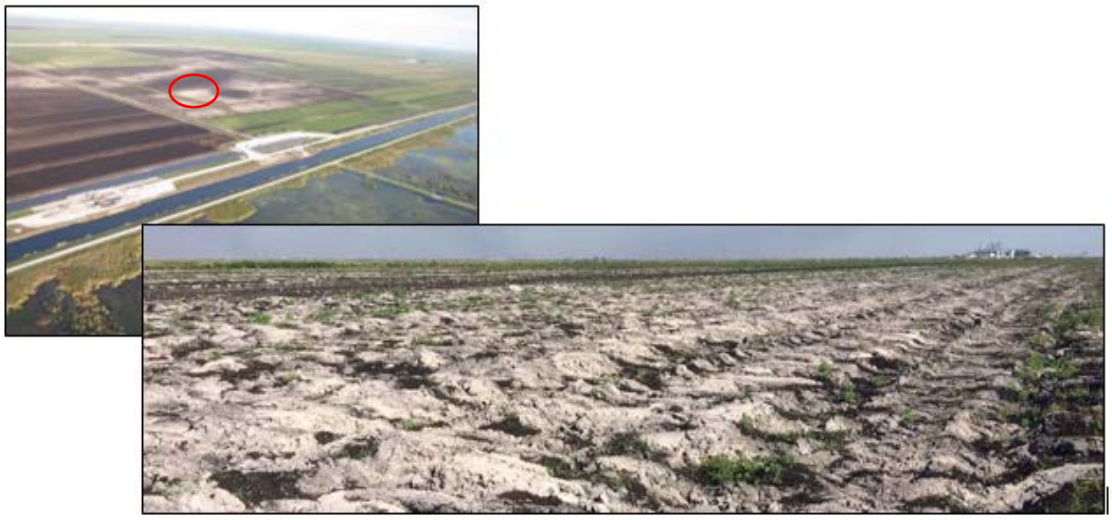

Figure 2. Aerial view (upper left, untilled) and close-up view (lower right, tilled) of former agricultural fields in STA-1WX1 where the soil was inverted to remediate for copper. Lighter areas of the lower reflect regions where marl was brought to the soil surface.

METHODS

CELL 7 SOIL INVERSION PILOT STUDY

Soil Sampling

On March 4, 2015, before the Cell 7 soil inversion pilot study, a total of 20 soil samples within the 0- to 15-centimeter (cm) soil depth were collected. An additional 20 soil samples were collected approximately 5 cm below the base of the cultivated layer. The pre-inversion soil samples collected from the western portion of the pilot study area were identified as PS1 through PS10, and the eastern samples were identified as PS11 through PS20 (**Figure 3**).

At each location, five samples were collected from the 0- to 15-cm depth with a stainless-steel auger (SFWMD and USFWS 2008). These samples were composited, and a subsample was collected for analysis. The location of each composite sample was recorded with a portable global positioning system device. SFWMD and USFWS developed a sampling protocol for the copper study and as a quality assurance/quality control (QA/QC) requirement, one field duplicate sample was collected for every 20 samples (5%). Samples were placed into tightly sealed polyethylene bags and stored in a cooler with ice and analyzed for pH, total organic carbon (TOC; SFWMD 2017), and TP.

Soil samples were also collected on March 12 and 17, 2015, following completion of the soil inversion pilot study (COC work ID = P77343). A set of 12 soil samples within the 0- to 15-cm soil depth and a subset of 12 samples from the 15- to 30-cm soil inversion depth were collected at the same locations as during the pre-inversion sampling (**Figure 3**). Soil samples were analyzed for pH, TOC, and TP analysis. Due to insufficient sample amount, post inversion subsurface samples from PS4 to PS8 and PS13 to PS16 locations were not analyzed.

After the completion of the pilot study, half of Cell 6 and all of Cell 7 (**Figure 1**, red dotted boundary) were inverted using an agricultural ripper (to break the hard layer including limerock), followed by disking using 1-meter diameter hardened steel blade (**Figure 4**). Additional random soil samples from each plot were collected at 0 to 15 cm (sample size [n] = 6) from the inverted area of Cell 6 representing a larger area

on February 22, 2017 (**Figure 5**). Samples were analyzed for TP, total calcium, percent ash, total carbon, and total nitrogen content (SFWMD 2017).

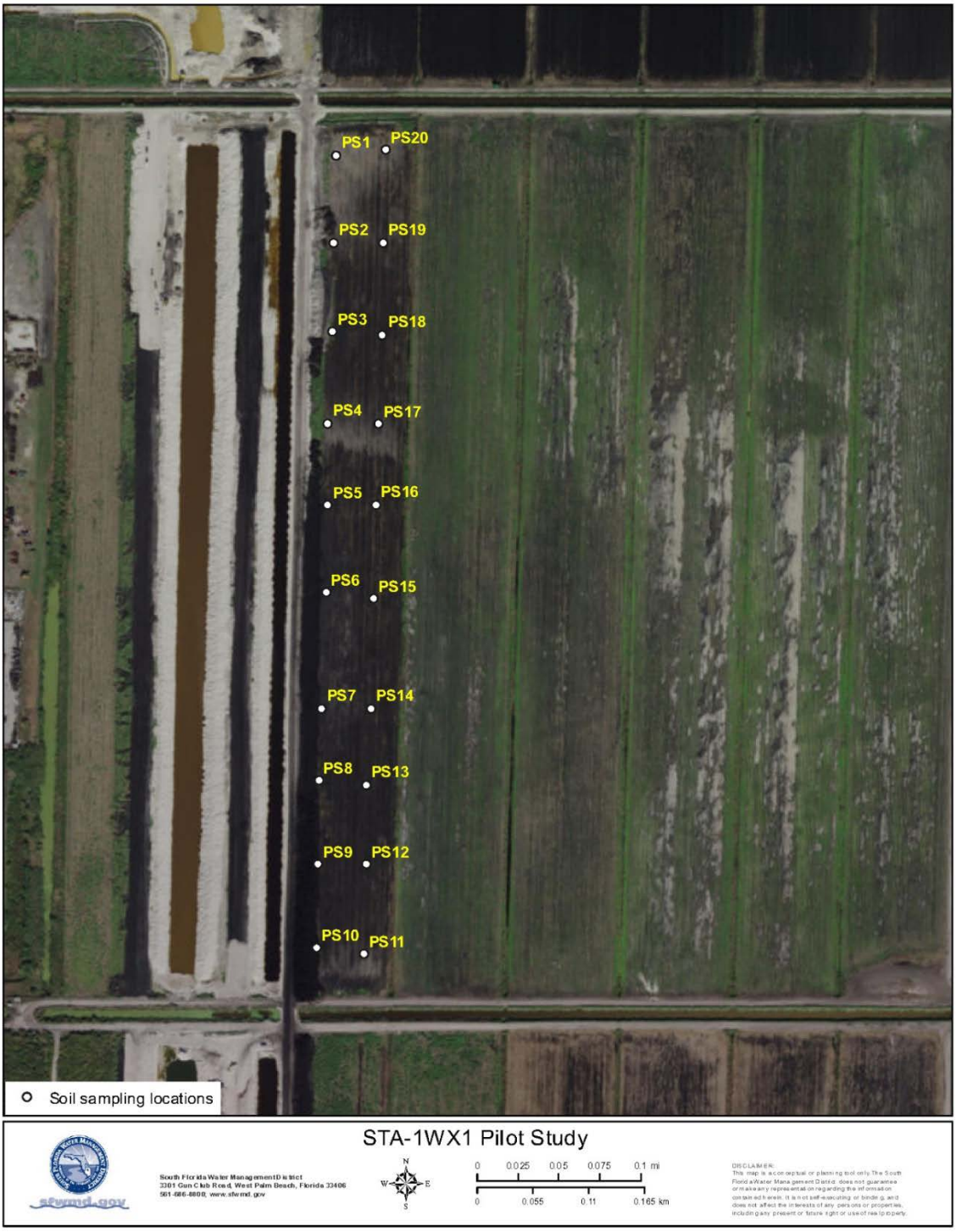

Figure 3. Soil sampling locations of pre- and post-soil inversion in Cell 7 of STA-1WX1. (Note: PS# stands for pilot study soil sampling location.)

Figure 4. Equipment used for STA-1WX1 soil inversion project.
In the top picture is a ripper and, in the bottom, picture is a soil inversion disk.

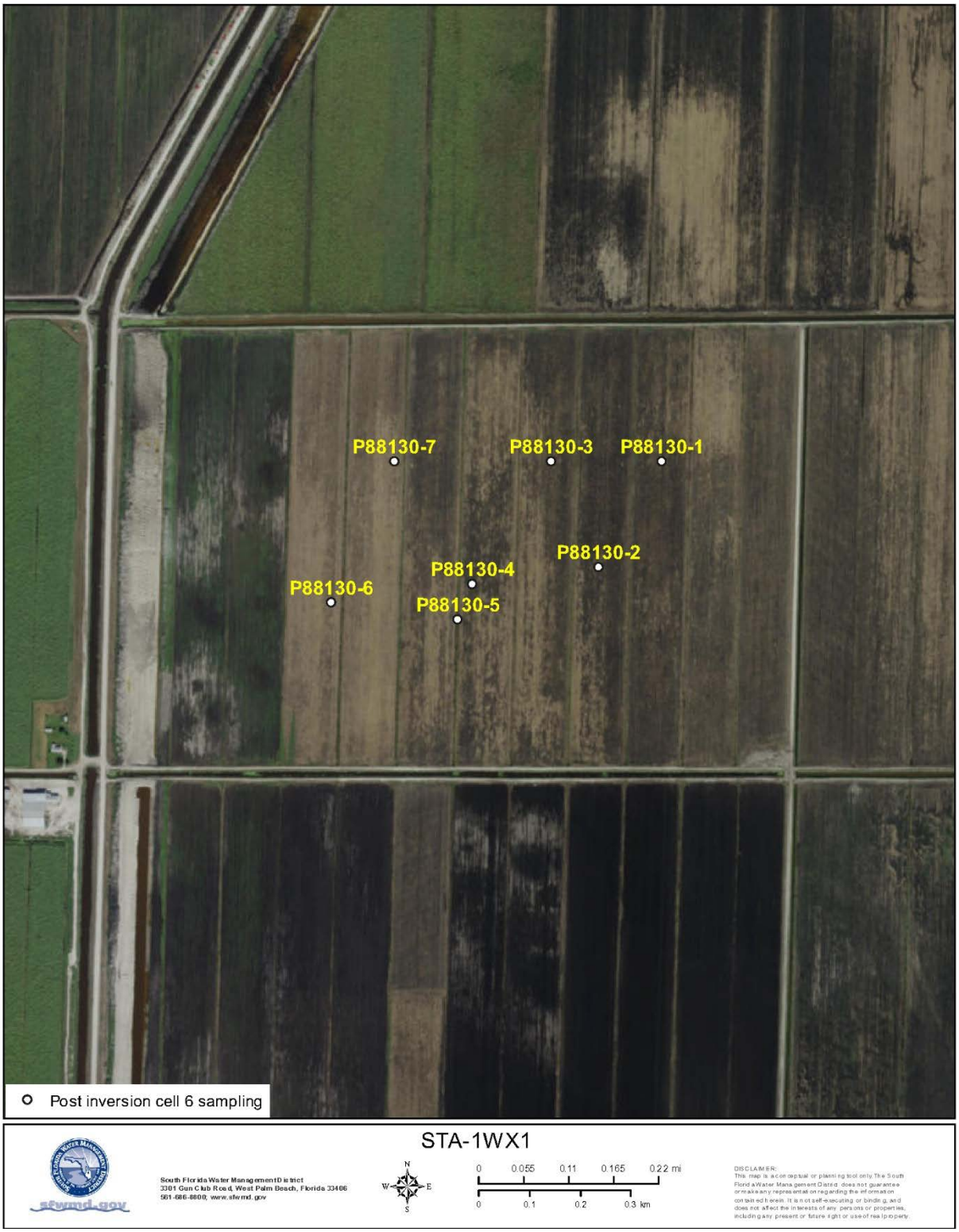

Figure 5. Soil sampling sites in the Cell 6 tilled area sampled on February 22, 2017.

SOIL CORE INCUBATION STUDY

On June 13 and 14, 2017, intact soil core samples were collected in three soil types within Cells 6 and 7: (1) where soil had not been inverted (approximately 450 ha), referred to as untilled; (2) where soil had been inverted with subsurface marl brought to the surface, referred to as inverted marl; and (3) where soil had been inverted, with subsurface peat brought to the surface, referred to as inverted peat (**Figure 6**). A total of eight locations per soil type were selected to account for spatial variability across the expansion area footprint. At one location for each soil type, triplicate cores were collected to estimate local field variability. Each intact soil core was collected using a 15-cm diameter acrylic tube driven into the soil to a depth of 15 to 20 cm. Soil cores were transported to DB Environmental's Gainesville, FL laboratory, and the Soil Core Incubation Study was initiated on June 19, 2017.

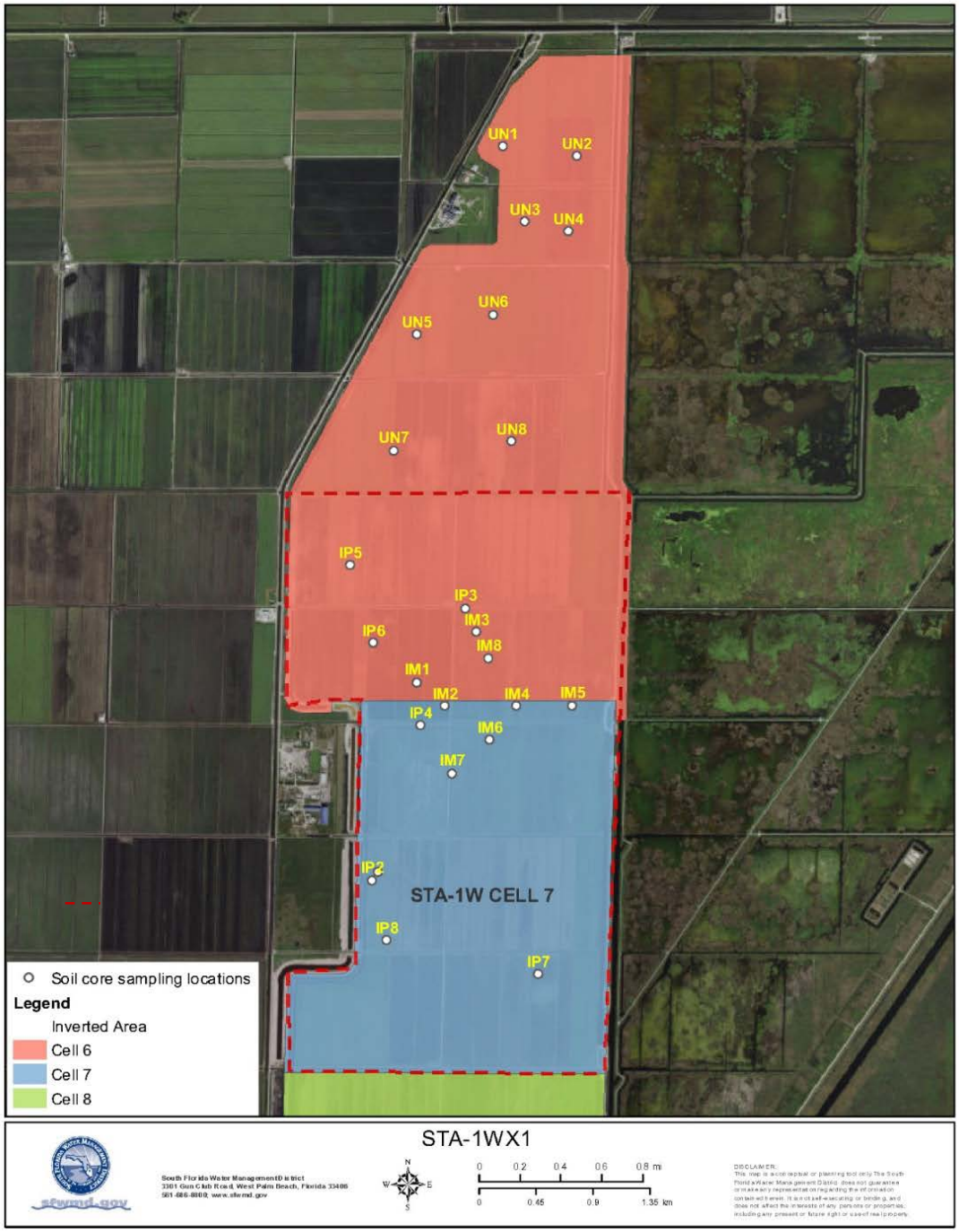

Figure 6. Soil core sampling locations in STA-1WX1 for the Soil Core Incubation Study and soil characterization. The red dotted line depicts the inverted area in Cells 6 and 7 for copper remediation purposes. (Whereas, UN = Untilled, IM = Inverted Marl, and IP = Inverted Peat.)

Soil cores were flooded to a depth of 30 cm with outflow water from STA-1W and incubated under dark, aerobic conditions to measure the potential soil P flux into the overlying water (**Figure 7**). Water was exchanged every 14 days for three cycles. The SRP concentrations of the water used for cycles 1, 2, and 3 were 3, 10, and 2 µg/L respectively. The surface water TP concentrations for the three cycles were 17, 18, and 10 µg/L respectively. Two "control" cores without soil were also incubated to document any change in

P concentration of the surface water not resulting from interactions with the soil (e.g., microbial growth on core walls).

Figure 7. Laboratory incubation setup and a close-up image of soil cores representing three treatments: UT = Untilled, IM =Inverted Marl, and IP = Inverted Peat.

To estimate P flux over time, overlying water was sampled at mid-depth from each core and analyzed for SRP at day 0, 3, 7, and 14 during the first two cycles. For the third cycle, SRP samples were sampled at day 0 and 14 from all cores, and at day 0, 3, and 7 in the triplicate cores (**Table 1**).

Table 1. Summary of sampling of incubated soil cores

Incubation Cycle	Parameter		
	SRP Water Sampling (day)	TP Water Sampling (day)	Soil Sampling
Cycle 1	0, 3, 7, and 14	0 and 14	Not applicable
Cycle 2	0, 3, 7, and 14	0 and 14	Not applicable
Cycle 3	0 and 14 0, 3, 7, and 14 for triplicates cores	0 and 14	TP and bicarbonate-extractable P (after the completion of the third cycle)

The P flux was calculated as follows:

P flux (mg P/m^2/day) = (C_t – C_0) x V /A

Where P Flux is the net release (positive values) or retention (negative values) rate per unit surface area of sediment core (mg P/m^2/day), C_t is the SRP concentration in the water column at time t, C_0 is the SRP concentration at time 0, V is the volume of water in the water column of the core tube, and A is the surface area of the sediment cores. Specifically, given the linearity of the SRP concentrations change over time, soil P flux rate was calculated as the difference between SRP concentration at Day 0 and 14 for each cycle, multiplied by the volume of water in the core (5.3 L) and divided by the soil surface area in the core (0.0176 m^2) and time interval (14 days), to yield a flux rate in mg P/m^2/day.

The water samples were analyzed for SRP and TP using SM 4500-P F (Rice et al. 2012) and EPA 365.2 (USEPA 1971) analytical methods, respectively. At the end of the Soil Core Incubation Study, the soil in each core was extruded and sectioned into 0- to 5-cm and 5- to 15-cm depth intervals and analyzed for TP using method EPA 365.2. The surficial soils (0- to 5-cm depth) were also extracted with 0.5-molar sodium bicarbonate ($NaHCO_3$) and the soil extract was analyzed for SRP to determine the labile, or "plant-available" fraction of soil P (Olsen et al. 1954).

SOIL PROFILE CHARACTERIZATION AND SAMPLING AT THE CELL 6 UNTILLED AREA

A soil profile survey of the untilled area of Cell 6 was conducted on September 6, 2017. Large soil pits were dug to the limerock using a long reach excavator (**Figures 8** and **9**). Once the pits were dug, the soil horizons were examined using standard soil classification methods and their relative thicknesses were measured. Soil samples from each horizon (soil layer) were collected using a stainless spatula and mixed to obtain a representative sample. A duplicate soil pit also was sampled to assess the field sampling precision. Samples were analyzed for TP, percent ash, total calcium, total magnesium, total iron, and total aluminum.

Figure 8. Soil profile sampling in untilled area of Cell 6 using a long reach hydraulic excavator.

Figure 9. Deep soil profile sampling locations (FD = field duplicate) in the untilled Cell 6 area.

DATA ANALYSIS

For the Cell 7 Soil Inversion Pilot Study, boxplots from pre-and post-inversion samples were developed in R software (R Core Team 2018) package ggplot2 (Wickham 2016) to show the measure of central tendency (median, mean), variability of each measured parameter along with its distribution. Pre-and post-inversion soil TP, TOC, and pH median values were compared using the Kruskal-Wallis Test. A probability factor [*p*] of 0.05 was considered significant. If the one-way analysis of variance (ANOVA) on ranks was significant ($p \leq 0.05$) in the Kruskal-Wallis test, then multiple comparisons of medians were performed as per Siegel and Castellan (1988) non-parametric procedure using R package "pgirmess" (Giraudoux, 2018).

Descriptive analyses of soil samples from the inverted (tilled) area of Cell 6 were also calculated using package "dplyr" (Wickham et al. 2018) in R software.

For the Soil Core Incubation Study, water SRP and TP concentrations during each individual incubation cycle were averaged for each soil type (Untilled, Inverted Peat, and Inverted Marl). The soil sample properties from the surface (0 to 5 cm) and subsurface (5 to 15 cm) layer were evaluated with box plots. Median values were compared using the R package "pgirmess" as described above.

Additionally, the spatial distribution of soil TP values of surface and subsurface soil layers was presented using ArcMap (ESRI 2015).

RESULTS AND DISCUSSION

CELL 7 SOIL INVERSION PILOT STUDY

After soil inversion, the median TP content of surface soil decreased significantly ([p] < 0.05) from 1,106 to 300 milligrams per kilogram (mg/kg; **Figure 10**). Correspondingly, median soil TP content of the subsurface soil samples increased significantly ($p < 0.05$) from 226 to 1,254 mg/kg. Similarly, the median TOC content of surface soil decreased from 48 to 29% after soil inversion (**Figure 11**). Soil median pH increased slightly from 7.55 to 7.67 in surface soil after soil inversion and decreased from 7.81 to 7.62 in subsurface soil (**Figure 12**); these differences were not significant.

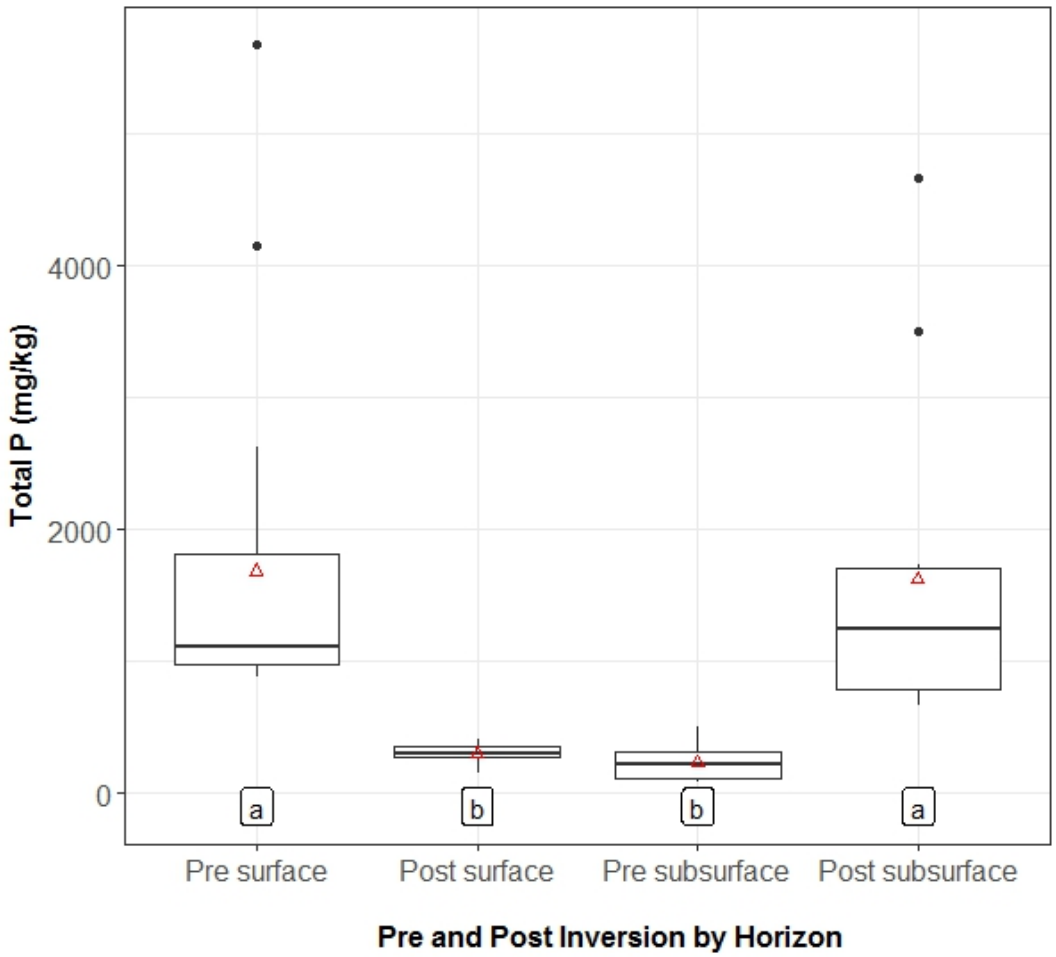

Figure 10. TP distribution of surface and subsurface soil samples before and after soil inversion in Cell 7 (Cell 7 Soil Inversion Pilot Study). In each box, the horizontal bar indicates the median, and the triangle indicates the mean. Median TP values with the same letter (Kruskal-Wallis test followed by post-hoc Siegel and Castellan 1988) are not significantly different ($p > 0.05$). The lower and upper limits of each box represent the first and third quartiles. The vertical lines (whiskers) represent the data range and the filled circle represents an outlier which is 1.5 times the length of the box from either end of the box.

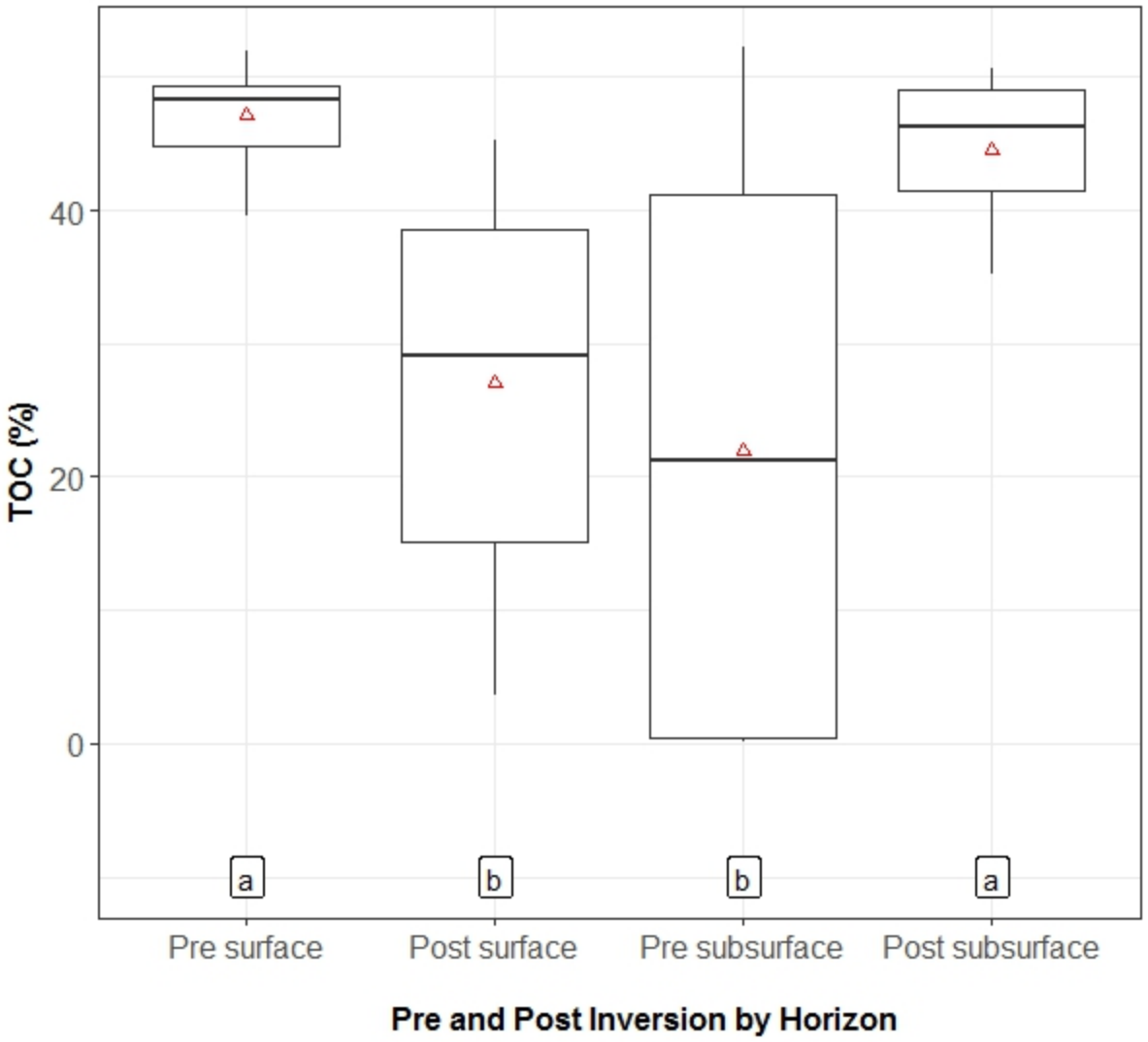

Figure 11. TOC distribution (% of dry weight) of surface and subsurface soil samples before and after soil inversion during the Cell 7 Soil Inversion Pilot Study. In each box, the horizontal bar indicates the median, and the triangle indicates the mean. Median TOC values with the same letter (Kruskal-Wallis test followed by post-hoc analysis Siegel and Castellan 1988) are not significantly different ($p > 0.05$). The lower and upper limits of each box represent the first and third quartiles. The vertical lines (whiskers) represent the data range.

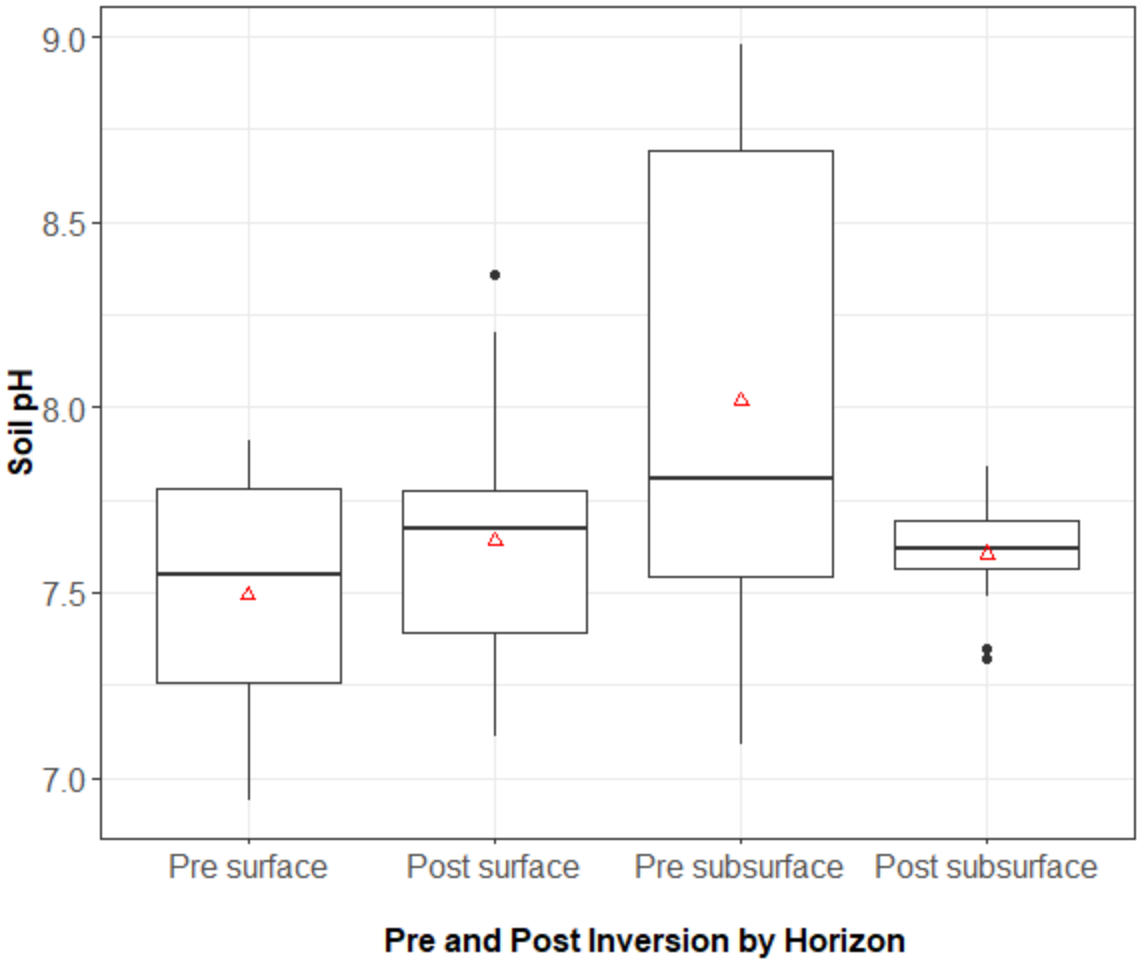

Figure 12. Soil pH distribution of surface and subsurface soil samples before and after soil inversion during the Cell 7 Soil Inversion Pilot Study. In each box, the horizontal bar indicates the median, and the triangle indicates the mean. The lower and upper limits of each box represent the first and third quartiles. The vertical lines (whiskers) represent the data range and the filled circle represents an outlier which is 1.5 times the length of the box from either end of the box. Kruskal-Wallis test indicated soil pH median values were not significantly different ($p > 0.05$), hence no post-hoc analysis was conducted.

CELL 6 POST INVERSION SOIL CHARACTERIZATION

The soil characterization results from the inverted area of Cell 6, based on the February 2017 sampling, were consistent with results from the Cell 7 Soil Inversion Pilot Study. The newly inverted surface soil (0 to 15 cm) had median TP of 596 mg/kg (**Table 2**), median percent total calcium of 6.7%, and percent total carbon content ranging from 24 to 51%. The median ash content was 33%, which also varied among the surface soil samples.

Table 2. Soil characteristics of the Cell 6 newly inverted surface soil (0 to15 cm; n = 6).

Sample ID	Total P (mg/kg)	Total Calcium (%)	Total Carbon (%)	Total Nitrogen (%)	Ash (%)
P88130-1	630	5.12	49.5	2.82	29.5
P88130-2	456	8.25	35.5	2.18	43.2
P88130-3	562	9.95	41.0	2.27	36.6
P88130-4	666	4.51	50.7	3.05	16.1
P88130-6	732	5.11	48.7	2.86	19.9
P88130-7	350	16.29	23.9	1.25	65.4
Mean	**566**	**8.20**	**41.6**	**2.41**	**35.1**
Median	**596**	**6.69**	**44.9**	**2.55**	**33.1**
Standard Deviation	**129**	**4.10**	**9.5**	**0.61**	**16.4**

SOIL CORE INCUBATION STUDY

During the first 14 days of incubation, the average water column SRP concentration increased from 3 µg/L to 11, 113, and 207 µg/L for inverted marl, inverted peat, and untilled soil cores, respectively (**Figure 13**). SRP in the water column of control cores were at or below detection limit (2 µg/l) for all but the first and second cycle water exchange (days 0 and 14; 3 and 9 µg/L, respectively), a result of the exchange water concentrations from STA-1W for days 0, 14, and 28 of 3, 10, and 2 µg/L, respectively. After two incubation cycles, the water column SRP of untilled cores averaged 121 µg/L. In the third cycle, SRP concentrations in the untilled cores were still the highest of all treatments and continued to increase from the beginning of each incubation cycle. At the end of the 6-week incubation period, the inverted marl cores' water column had the least amount of average SRP (6.2 µg/L), whereas, the untilled cores had the highest average SRP concentrations (147 µg/L). Over three incubation cycles, average TP concentrations in the water column after 14 days were 12, 13, 68, and 156 µg/L for control, inverted marl, inverted peat, and untilled cores, respectively (**Figure 14**). The average SRP flux rates for the initial 14-day period was 0.2 milligrams P per square meter per day (mg $P/m^2/d$) for the inverted marl treatment, and 4.4 mg $P/m^2/d$, for the untilled treatment (**Figure 15**). The SRP flux remained low during the three cycles for inverted marl cores (average P flux was 0.10 mg $P/m^2/d$). The SRP flux in the inverted peat cores (1.6 mg $P/m^2/d$) was also lower than the untilled cores (3.3 mg $P/m^2/d$).

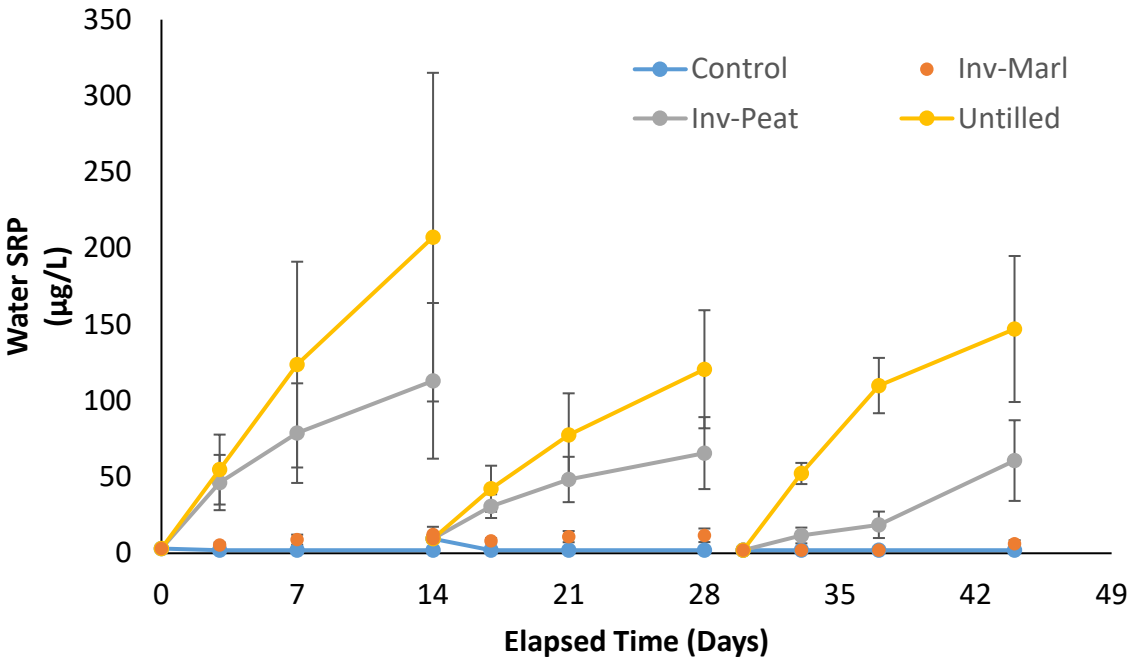

Figure 13. Water column SRP concentrations during the 42 days of incubation under dark, aerobic conditions. The values represent the mean (± standard error) of eight cores from inverted (Inv) Peat, Inverted Marl, untilled soils, and two control cores (surface water without soil).

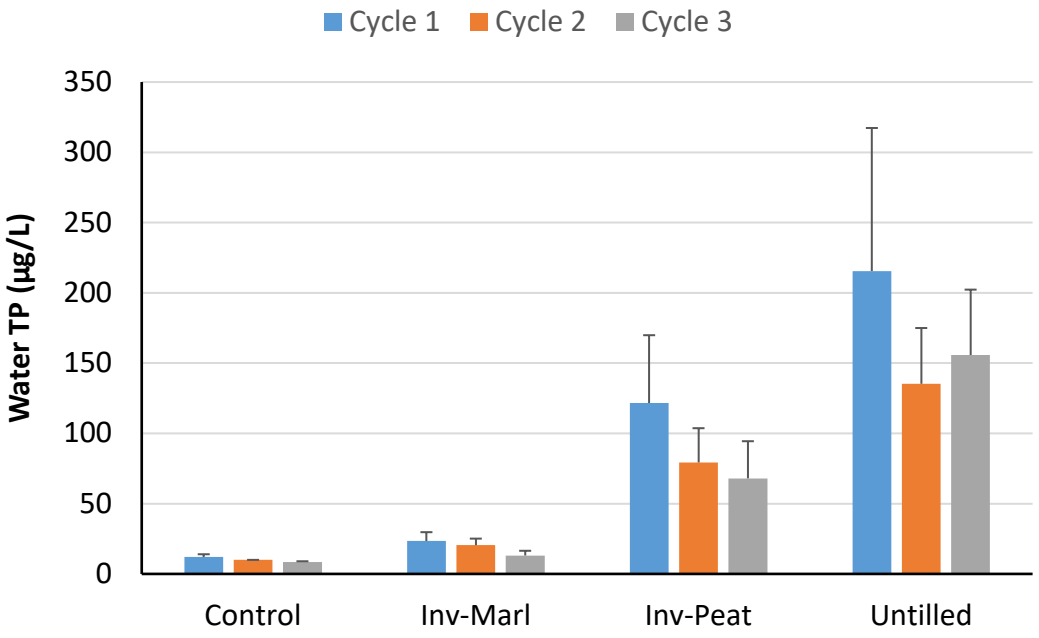

Figure 14. Water column TP concentrations at the end of each three consecutive incubation cycles. The values represent mean (+ standard error) of eight cores from inverted (Inv) Marl, Inverted Peat, Untilled soil, and two control cores (surface water without soil core) measured after 14 days of dark, aerobic incubation.

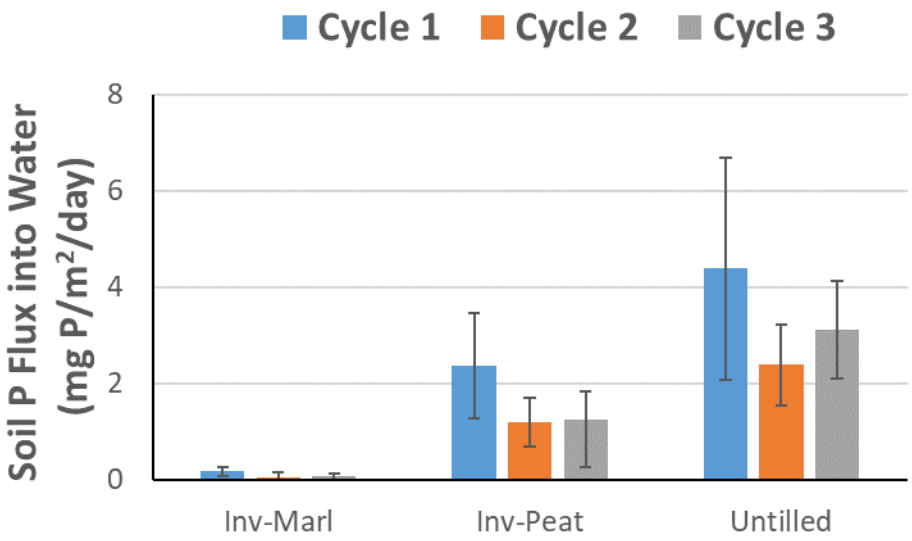

Figure 15. Soil diffusive P flux rates measured in intact cores of inverted (Inv) Marl or Peat and Untilled soils, collected in June 2017, flooded and incubated in the laboratory under dark, aerobic conditions for three 14-day cycles.

Surface soil in the inverted marl cores had the lowest median TP concentrations (160 mg/kg), which was significantly lower ($p < 0.05$) than in the inverted peat (527 mg/kg) and untilled cores (830 mg/kg) (**Figure 16**). Similarly, the median TP concentration of subsurface soils in the inverted marl cores (299 mg/kg) was significantly lower ($p < 0.05$) than in the inverted peat (625 mg/kg) and untilled cores (729 mg/kg). Bicarbonate extractable P in surface soil followed a similar distribution as TP with higher values in the untilled soil than the inverted soils (**Figure 17**). Two of the inverted peat soil core samples exhibited higher bicarbonate-extractable P than the rest of the samples, which could have caused higher SRP concentrations in the incubating waters of the Soil Core Incubation Study. Bicarbonate-extractable P is a measure of the amount of labile (or plant-available) P in soil. As plant uptake depletes P in the soil solution, loosely-bound P in the soil can be released as a response. This labile pool of soil P has been correlated with soil P flux to the water column for neutral to calcareous soils (Sharpley et al. 2002). The spatial distribution of soil surface (0 to 5 cm) and subsurface soils (5 to 15 cm) TP showed the predominance of higher P content at the surface of untilled areas (**Figures 18** and **19**, respectively).

The vast majority of P released from the soil to the water column in these core incubations, conducted under dark conditions, was measured as SRP. Data on dissolved organic P and particulate P fractions are not presented in this Appendix, but after the first 14 days of incubation, SRP was 96% of the total P concentration in the cores with the highest P release rates (untilled soil cores). The dissolved organic phosphorus concentration, determined as the difference between the total soluble P and SRP, was 5 µg/L in both the initial reflood water and the control columns after 14 days, whereas the water above soils of all three types contained 7-8 µg/L after 14 days.

The data indicate that the lower SRP released from the inverted marl soil was likely due to the presence of low labile P in the soil and presence of high amounts of associated cations with carbonates, which has the potenital to adsorb P or decrease the solubility of P compounds (Lindsay 1979). During the soil incubation, inverted marl soils had the lowest levels of P fluxed into the water column followed by inverted peat soils. Estimated fluxes from inverted peat and marl were less than estimated fluxes from untilled soils. High labile P content in untilled soils in the STA-1WX1 indicates that this top layer of soil has the potential to release more P than the underlying peat or marl soil once the area is flooded, particularly with low P

water, which is typical of the current discharge from existing STA-1W flow-ways. Consequently, soil inversion reduced the release of TP into the water column during incubation.

The Cell 7 Soil Inversion Pilot Study demonstrated that subsurface peat and marl, which had significantly lower median TP content than the surface muck layer ($p < 0.05$), could be moved to the surface while surficial agricultural topsoil could be buried to lower depths. Thus, inversion has the potential to minimize the release of P into the water column during flooding as shown in the Soil Core Incubation Study.

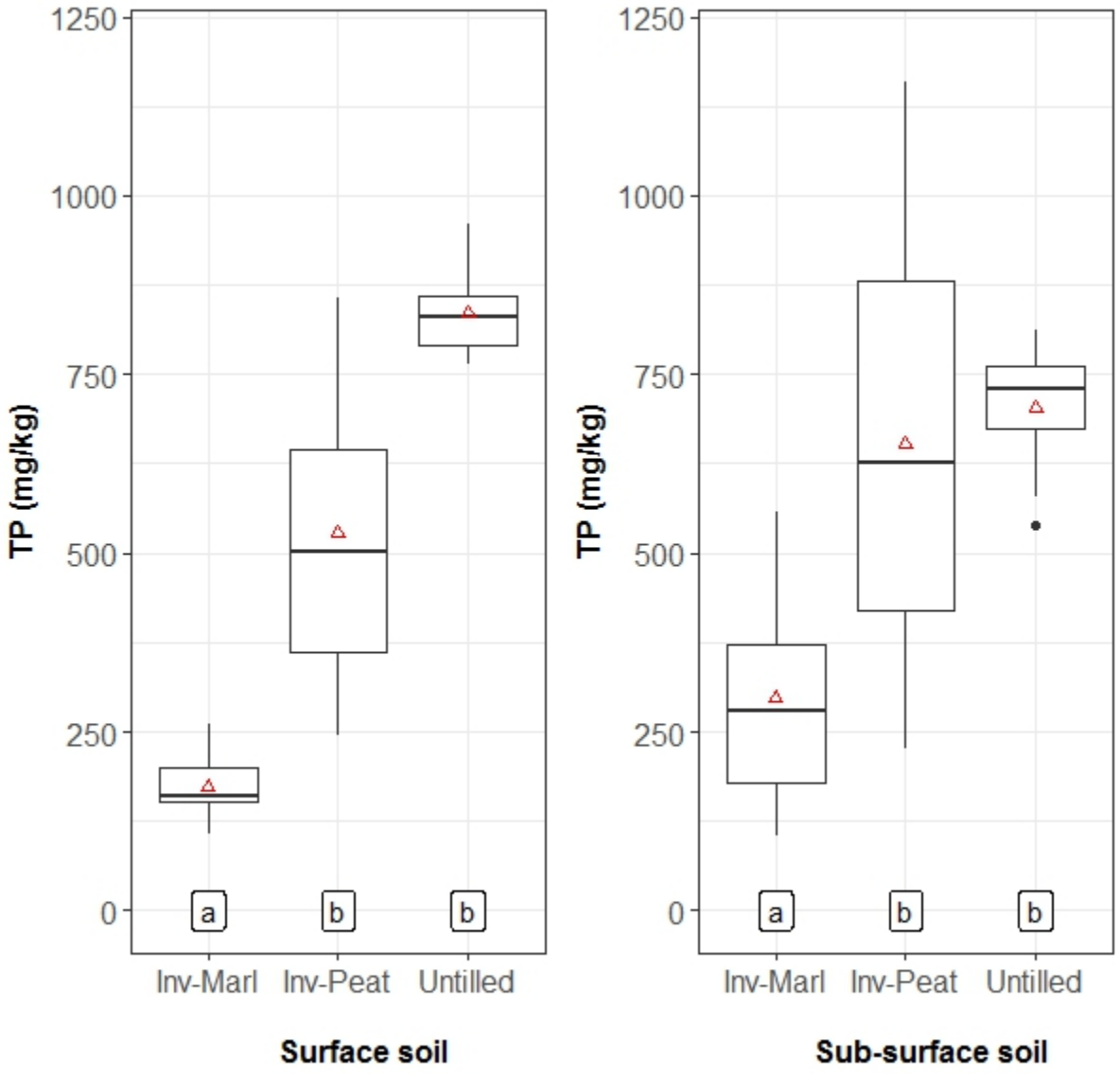

Figure 16. Box plot of TP in the surface (0 to 5 cm) and subsurface (5 to 15 cm) soil layers in the cores (Inv = inverted) at the end of third cycle of incubation. In each box, a horizontal bar indicates the median, and a triangle indicates the mean. Medians with the same letter are not significantly different at the 0.05 probability level (Kruskal-Wallis test followed by post-hoc analysis Siegel and Castellan 1988). The lower and upper limits of the boxes represent the first and third quartiles of soil TP. The vertical lines (whiskers) represent the data range and the filled circle represents an outlier which is 1.5 times the length of the box from either end of the box.

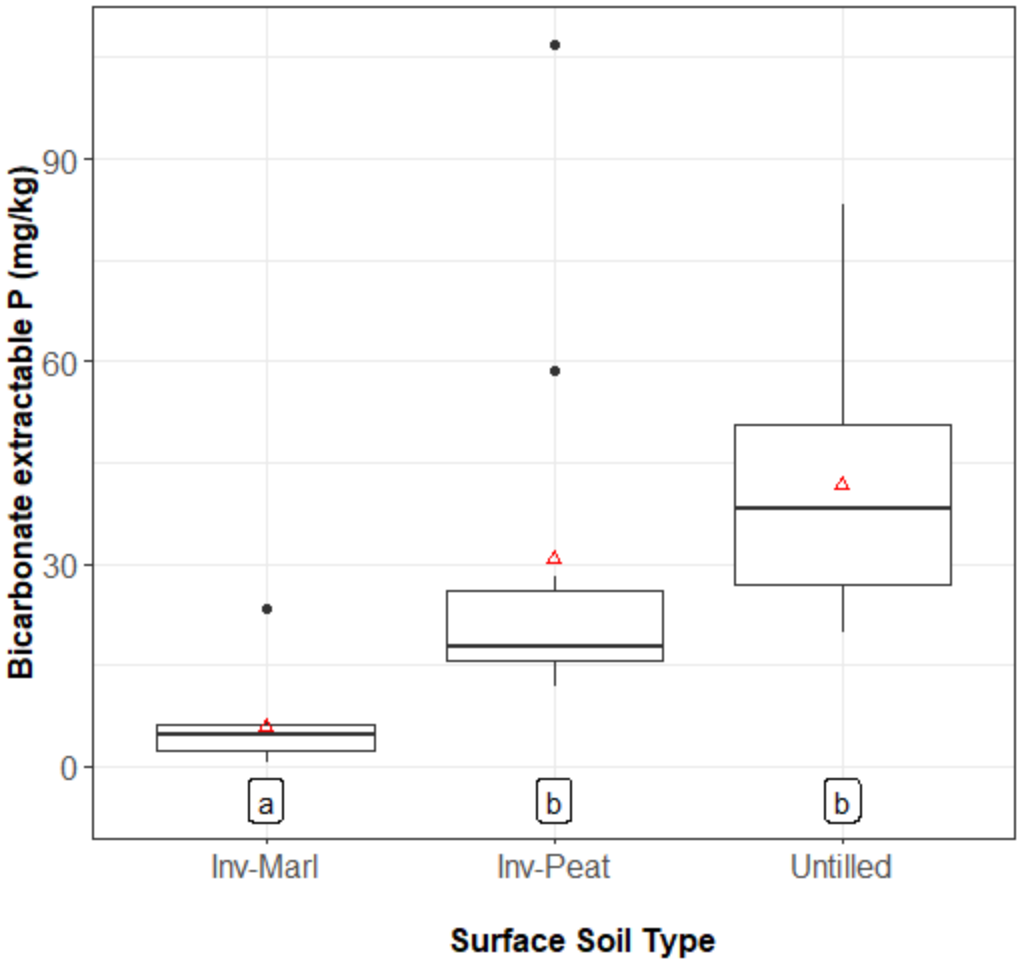

Figure 17. Box plot of bicarbonate extractable P in the surface (0 to 5 cm) soil layers in the cores at the end of third cycle of incubation. In each box, a horizontal bar indicates the median, and red triangle indicates the mean. Medians with the same letter are not significantly different at the 0.05 probability level (Kruskal-Wallis test followed by post-hoc analysis Siegel and Castellan 1988). The lower and upper limits of the boxes represent the first and third quartiles of bicarbonate extractable P. The vertical lines (whiskers) represent the data range and the filled circle represents an outlier which is 1.5 times the length of the box from either end of the box.

Figure 18. Spatial distribution of TP in the surface soil (0 to 5 cm) in inverted marl (IM), and inverted peat (IP) and untilled soil (UN) samples. The red dotted line depicts the inveretd area in Cells 6 and 7 for copper remediation purposes, whereas Red, Blue and Green shaded color represents Cells 6-8 respectively.

Figure 19. Spatial distribution of TP in the subsurface soil (5 to 15 cm), in inverted marl (IM), inverted peat (IP), and untilled (UN) soil samples. The red dotted line depicts the inveretd area in Cells 6 and 7 for copper remediation purposes, whereas Red, Blue and Green shaded color represents Cells 6-8 respectively.

SOIL PROFILE CHARACTERIZATION AND SAMPLING AT CELL 6 UNTILLED AREA

Cell 6 soils were predominantly muck at the surface, peat in the middle, and marl at the bottom of the soil profile. Surface soil was mainly composed of loosely bound muck. The marl layer exhibited multiple shades of gray ranging from light gray clayey marl to light tan marl (**Figure 20**). The muck layer had a median thickness of 25 cm (**Table 3**). Some of the marl layers also contained limestone (visual observation). The marl layer thickness ranged from 19 to 28 cm, and the peat layer thickness varied from 23 to 36 cm.

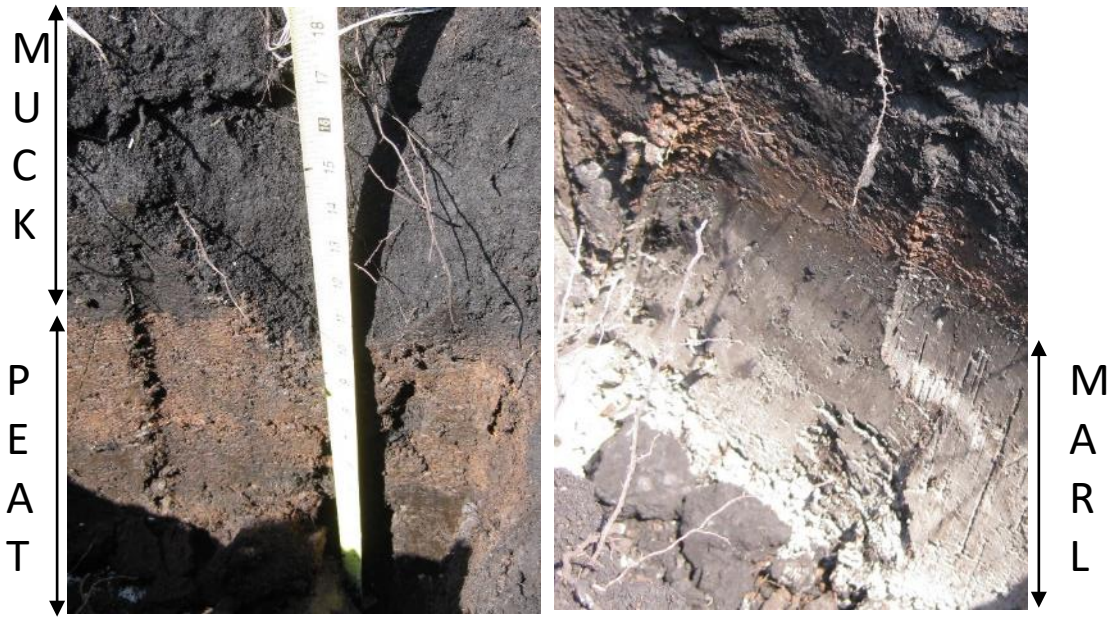

Figure 20. Vertical soil profile in STA-1WX1 Cell 6 showing the dominant soil layers: muck and peat (left) and muck, peat, and marl (right).

Table 3. Median values of soil properties of major soil layers in untilled areas of Cell 6 (n = 5).

Soil Layer	TP (mg/kg)	Calcium (%)	Magnesium (%)	Iron (%)	Aluminum (%)	Ash (%)	Thickness [a] (cm)
Muck	819	4.89	0.337	0.401	0.257	16.6	25.4
Peat	236	4.30	0.414	0.234	0.187	15.0	30.5
Marl	147	19.4	1.63	0.901	1.14	89.0	20.3

a. Thickness refers to the width of each soil layer. Ash refers to the inorganic residue remained after water and organic matter burning. The values represent the median derived from five locations.

The muck soil layer contained the highest TP content (median = 819 mg/kg) of all the layers. In contrast, the marl layer had the lowest TP content (median = 147 mg/kg), followed by the peat layer (236 mg/kg). The TP concentration decreased with soil depth (**Figure 21**), while the calcium concentration increased with soil depth (**Figure 22**). The marl layer had a higher median total calcium concentration (19%) than the muck (4.9%) and the peat (4.3%) layers. The marl layer also had higher median total magnesium, total iron, and total aluminum concentrations than the muck and peat (**Table 3**).

Data indicate that soil inversion of the remaining untilled portion of Cell 6 in STA-1WX1 has the potential to reduce the TP concentrations in the top 15 cm of the soil surface and increase calcium and other cation contents in the surface soil, which can provide sorption sites for P removal from the water column. Soil inversion, particularly where the sublayer is marl, resulted in a reduced flux of SRP and TP into the water column over a 6-week incubation period. Therefore, soil inversion is expected to help reduce the release of P from the soil to the water column once the area is flooded and benefit the performance of Cell 6. To study the long-term effects of soil inversion on P release, a long-term monitoring experiment of untilled versus tilled areas will be initiated after the cells are flooded (SFWMD 2018).

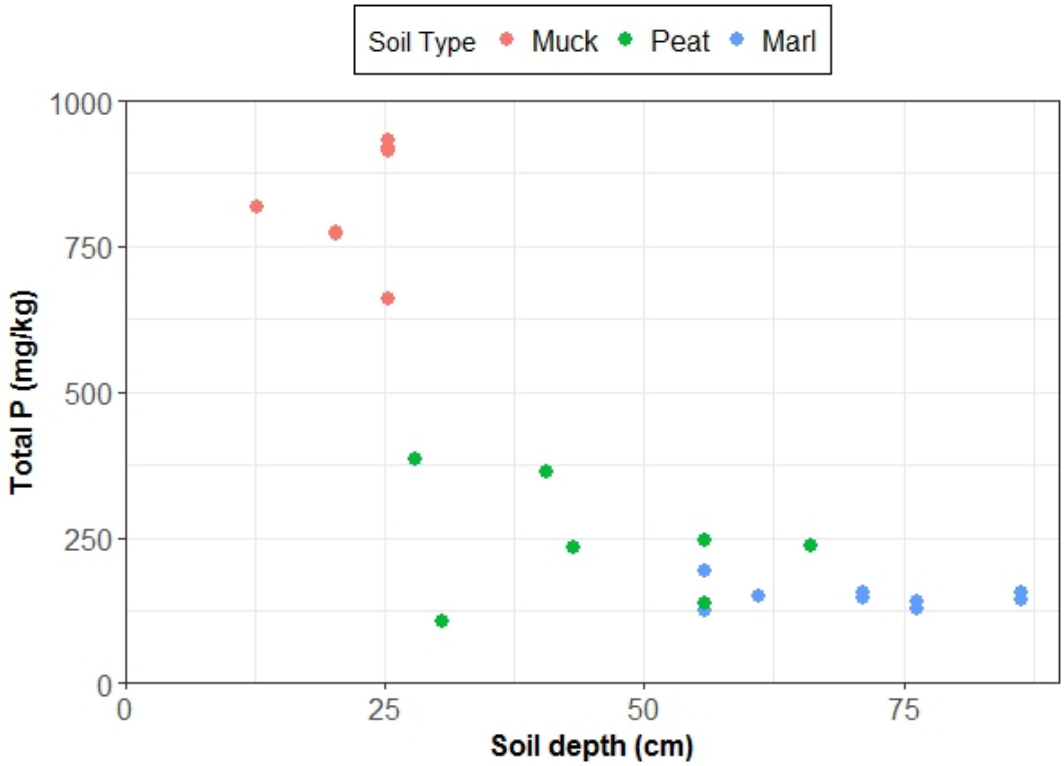

Figure 21. Soil TP concentrations of all samples at varying depth of the untilled areas in Cell 6 sampled on September 2017.

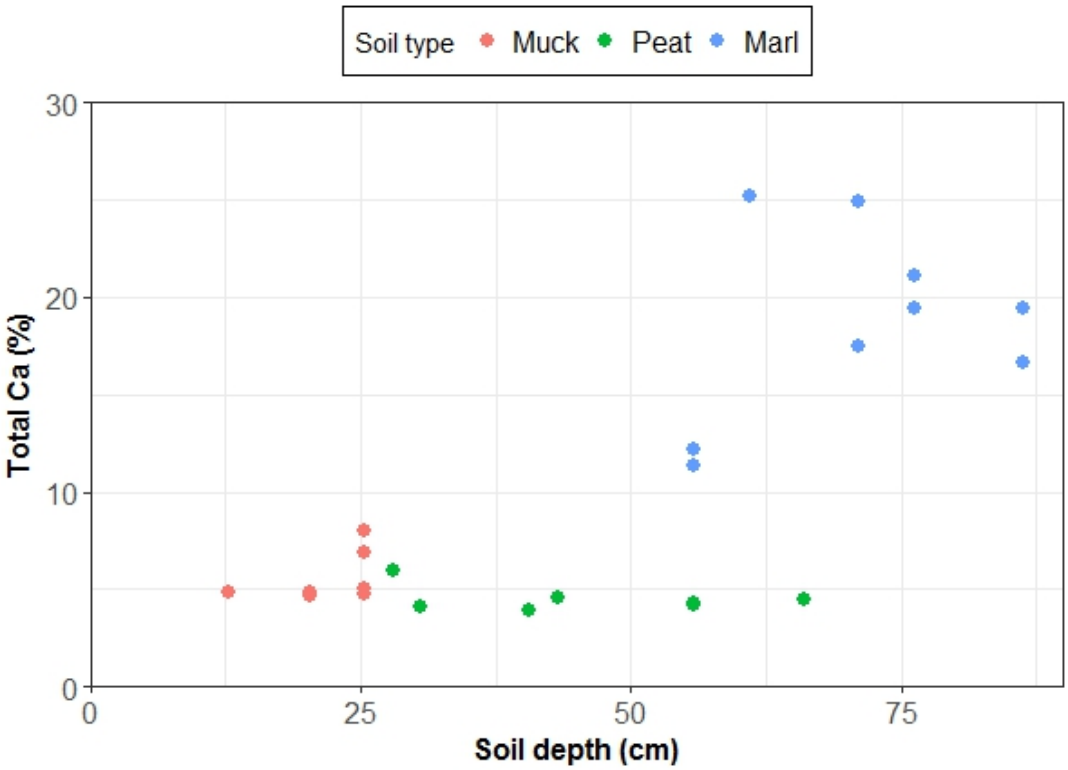

Figure 22. Soil total calcium concentrations of all samples at varying depth of the untilled areas in Cell 6 sampled in September 2017.

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