Linking Phosphorus Storage Mechanisms with Removal Performance in Everglades Stormwater Treatment Wetlands

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Cell 2 of STA-1E
(South Florida Water Management District)

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Introduction

- Constructed wetlands (CWs)
- Vegetation types
  - Emergent aquatic vegetation (EAV)
  - Submerged aquatic vegetation (SAV)
- Forms of phosphorus (P)
  - Inorganic (Pi) and organic (Po)
  - Determined using operationally defined fractionation schemes

SAV and EAV in Cell 4 of STA-2
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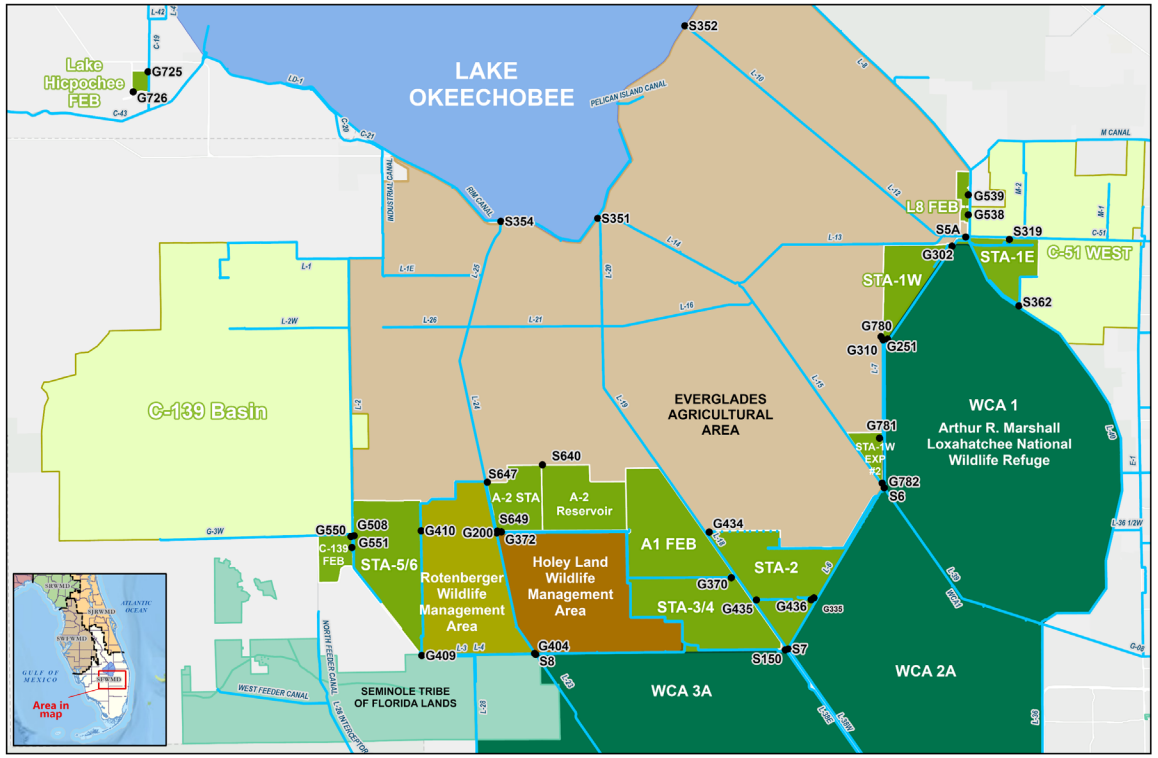
Case Study: Everglades Stormwater Treatment Areas (STAs)

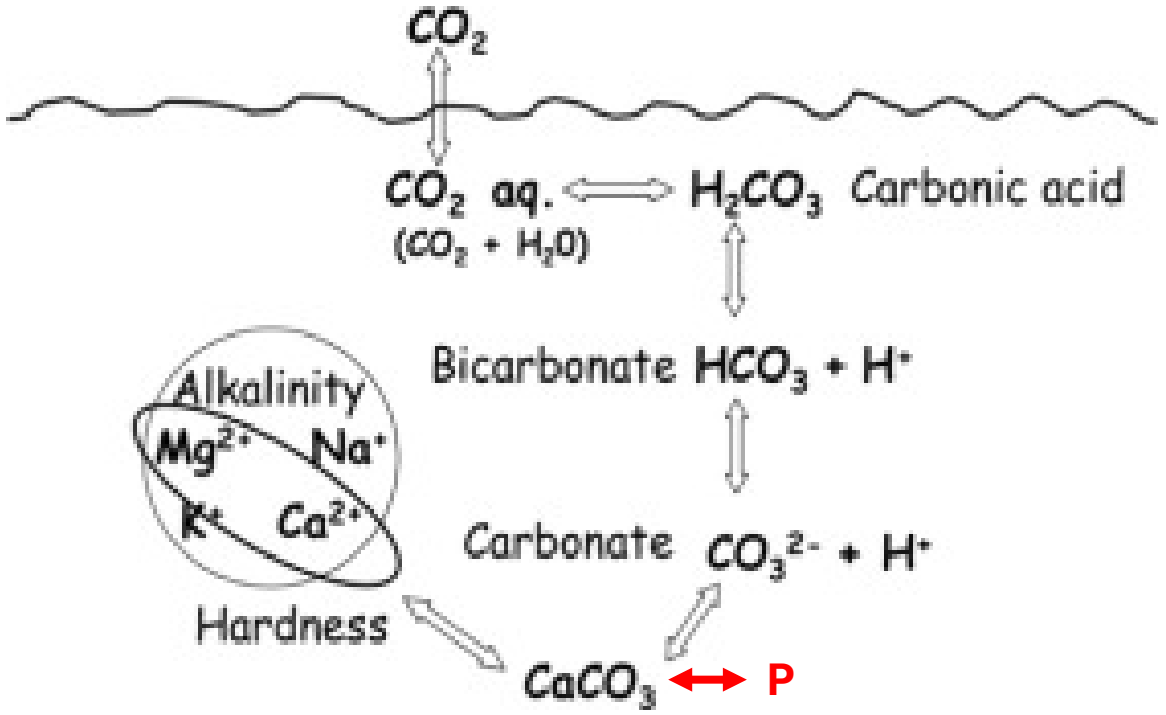


Map of Everglades Stormwater Treatment Areas in relation to the Everglades Agricultural Area and Everglades Protection Area
(South Florida Water Management District)

- South Florida, USA
- Designed to remove nutrients from Everglades Agricultural Area prior to entering Everglades Protection Area (EPA)
  - Discharge very low P concentration water into EPA
- Currently 5 Everglades STAs in operation
  - Each Everglades STA consists of flow-ways (FWs) divided into cells
- Have removed 3,000+ metric tons of P over their period of record
- Can they meet water quality-based effluent limit (WQBEL) starting in 2026?

Prior Everglades STA Research

- Accreted soil P storage
  - Mechanisms associated with P forms
    - EAV systems: biotic
    - SAV systems: abiotic calcium carbonate ($CaCO_3$)-associated
      - Underwater photosynthesis resulting in co-precipitation of P with $CaCO_3$
- P removal performance
- **<u>Unknown:</u>** Relationship between P removal performance of Everglades STAs and forms/trends of accreted soil P being stored



Schematic of underwater calcium carbonate formation
(Isahak et al., 2015)

Objective and Hypotheses

Collecting sediment cores in Cell 6 of STA-2
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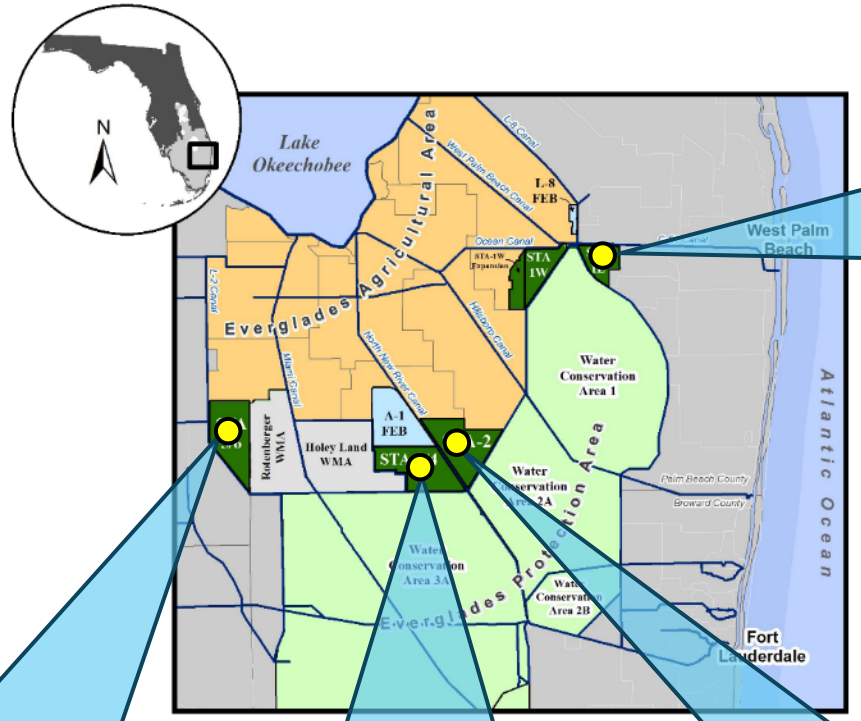
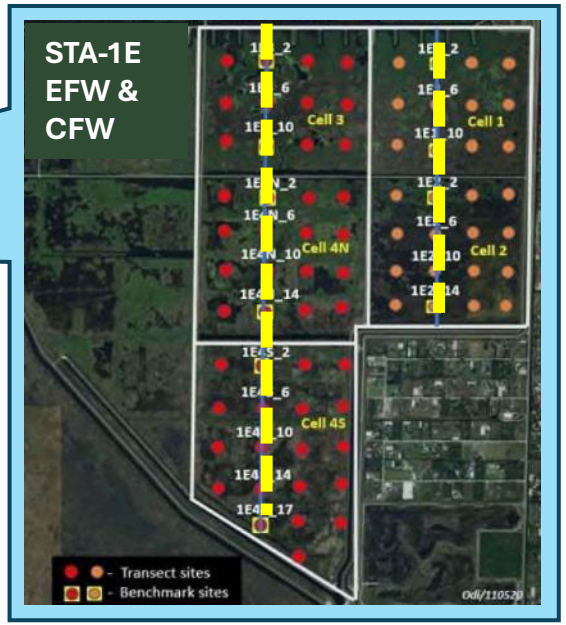
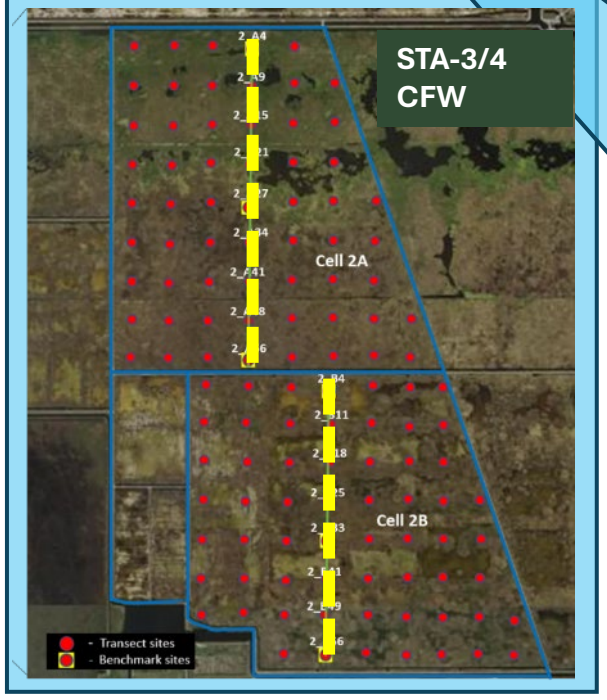
- **Objective:** Evaluate the effect of nutrient loading on forms of P and mechanisms of P storage in accreted soil in Everglades STA FWs of varying performances
- **Hypotheses:**
  - Better performing FWs
    - P forms:
      - Acid-extractable
      - Residual
    - Abiotic $CaCO_3$-associated mechanism
  - Under-performing FWs
    - P forms:
      - Bicarbonate
      - Microbial biomass
      - Alkali-extractable
    - Biotic mechanisms

Study Area


N
Lake Okeechobee
Everglades Agricultural Area
L-8 FEB
West Palm Beach
STA 1W
Water Conservation Area 1
Water Conservation Area 2A
Water Conservation Area 3A
Water Conservation Area 2B
Everglades Protection Area
Rotenberger WMA
Holey Land WMA
A-1 FEB
STA 5
STA 6
Atlantic Ocean
Fort Lauderdale
Palm Beach County
Broward County


STA-1E
EFW &
CFW
Cell 3
Cell 1
Cell 4N
Cell 2
Cell 4S
Transect sites
Benchmark sites

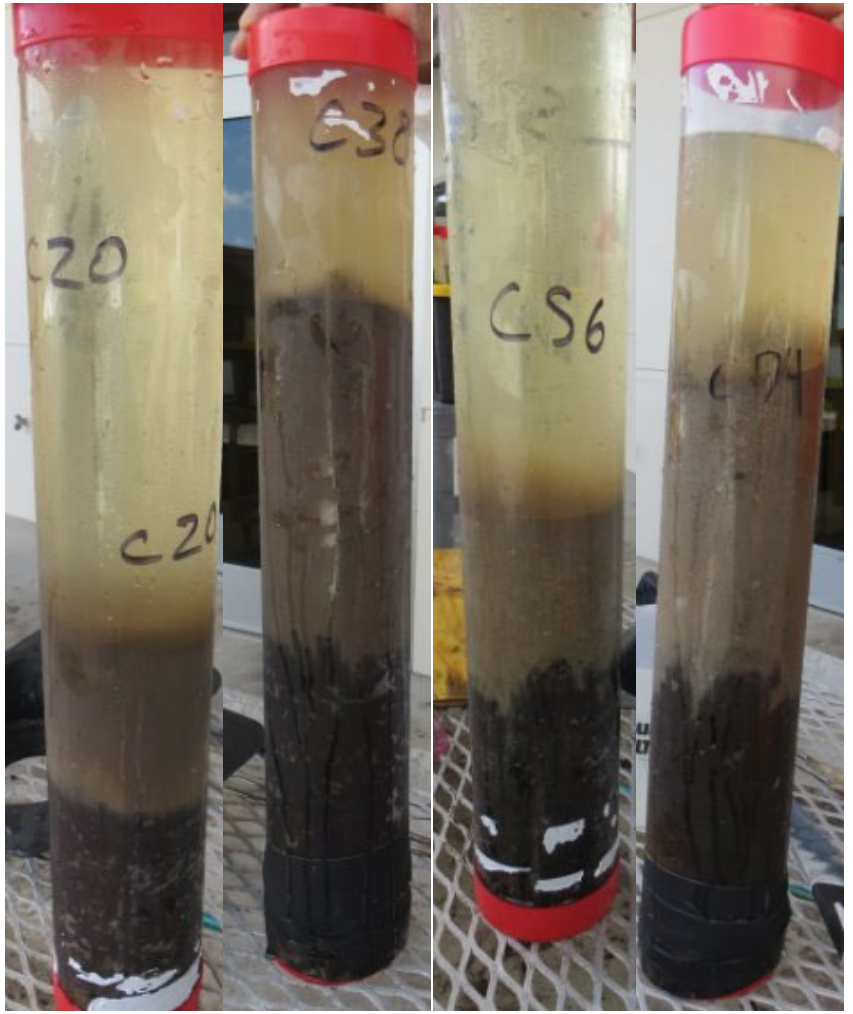

Cell 1A
Cell 1B
1A_8
1A_9
1A_10
1A_11
1A_12
1A_13
1A_14
1B_36
1B_37
1B_38
1B_39
1B_40
1B_41
1B_42
Transect sites
Benchmark sites
STA-5/6 FW1


STA-3/4
CFW
Cell 2A
Cell 2B
Transect sites
Benchmark sites


STA-2
FWs 3 & 4
Cell 5
Cell 6
Cell 4
Cell 3
Transect sites
Benchmark sites

Methods: Performance Designations + Soil Sampling and Chemical Analysis

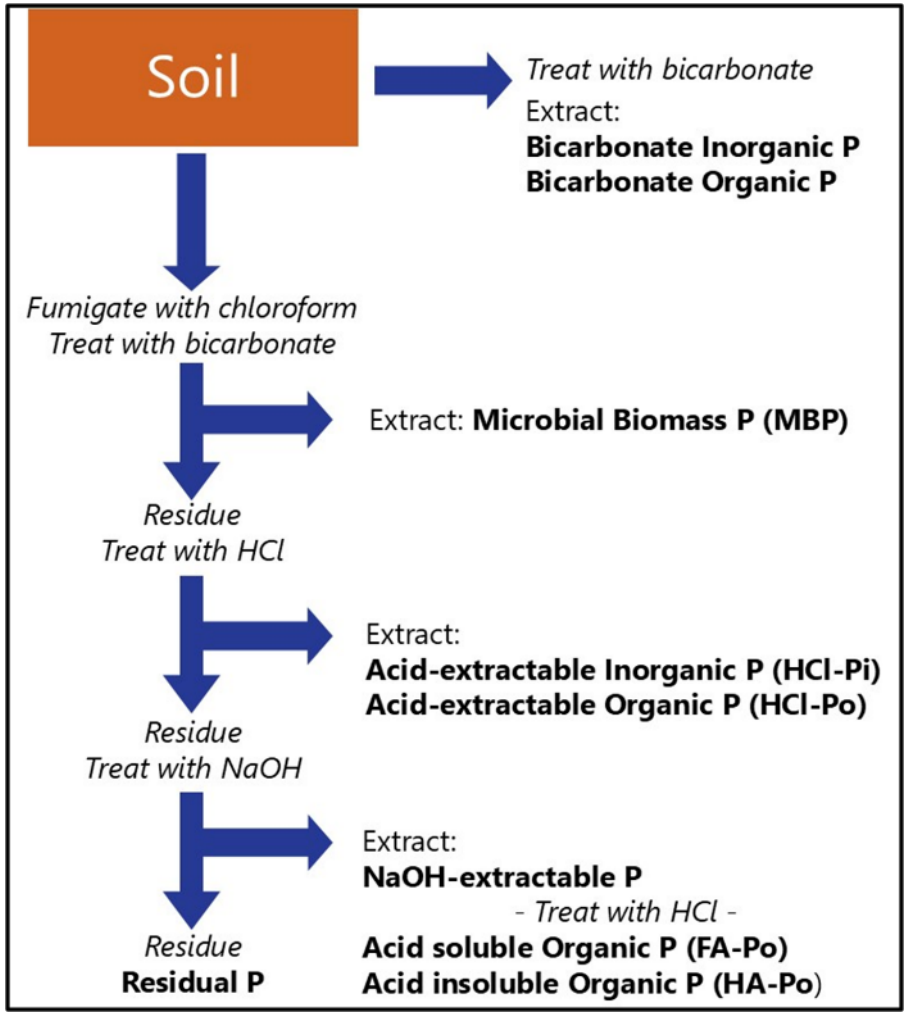
- Performance designations determined based on average outflow total phosphorus (TP) concentrations and % TP loads retained from their startup until WY2021 when sampling occurred
- Intact triplicate cores of accreted soil collected along a transect in May-December 2021
  - Transect sampling stations were considered repeated measures
- Chemical analysis
  - Total nutrients (Al, C, Ca, Fe, K, Mg, N, P, and S)
  - Ammonium oxalate extractable Al, Fe, P



Intact soil cores collected for this project

Methods: Soil Phosphorus Fractionation

- Modified from Ivanoff et al. (1998) and Reddy et al. (2019)
- P was separated into 8 forms based on sequential soil extractions
- Storage of each P form as a % of TP was calculated



Phosphorus fractionation scheme

Methods: Statistical Analysis

- Kruskal-Wallis test was used to compare effect of performance on storages of P forms
  - Dunn's test was used for multiple means comparison
- Principal component analysis (PCA) was used to ordinate sites according to P forms and selected biogeochemical parameters

SAV in Cell 8 of STA-2
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Results: Performance Designations

- **Well-performing:**
  - < 19 µg L^{-1} outflow TP concentration
  - > 75% TP load retained
  - STA-2 FW4
  - STA-3/4 CFW
- **Variable-performing:**
  - > 19 µg L^{-1} outflow TP concentration
  - > 75% TP load retained
  - STA-1E EFW
  - STA-2 FW3
- **Under-performing:**
  - > 19 µg L^{-1} outflow TP concentration
  - < 75% TP load retained
  - STA-1E CFW
  - STA-5/6 FW1

Performance designations of STA-1E EFW, STA-1E CFW, STA-2 FW3, STA-2 FW4, STA-3/4 CFW, and STA-5/6 FW1 based on water quality parameters from their startup until WY2021

FW	Average Outflow TP Concentration (µg L^{-1})	Average TP Load Retained (%)	Performance Designation

Results: Effect of performance on storages of P forms

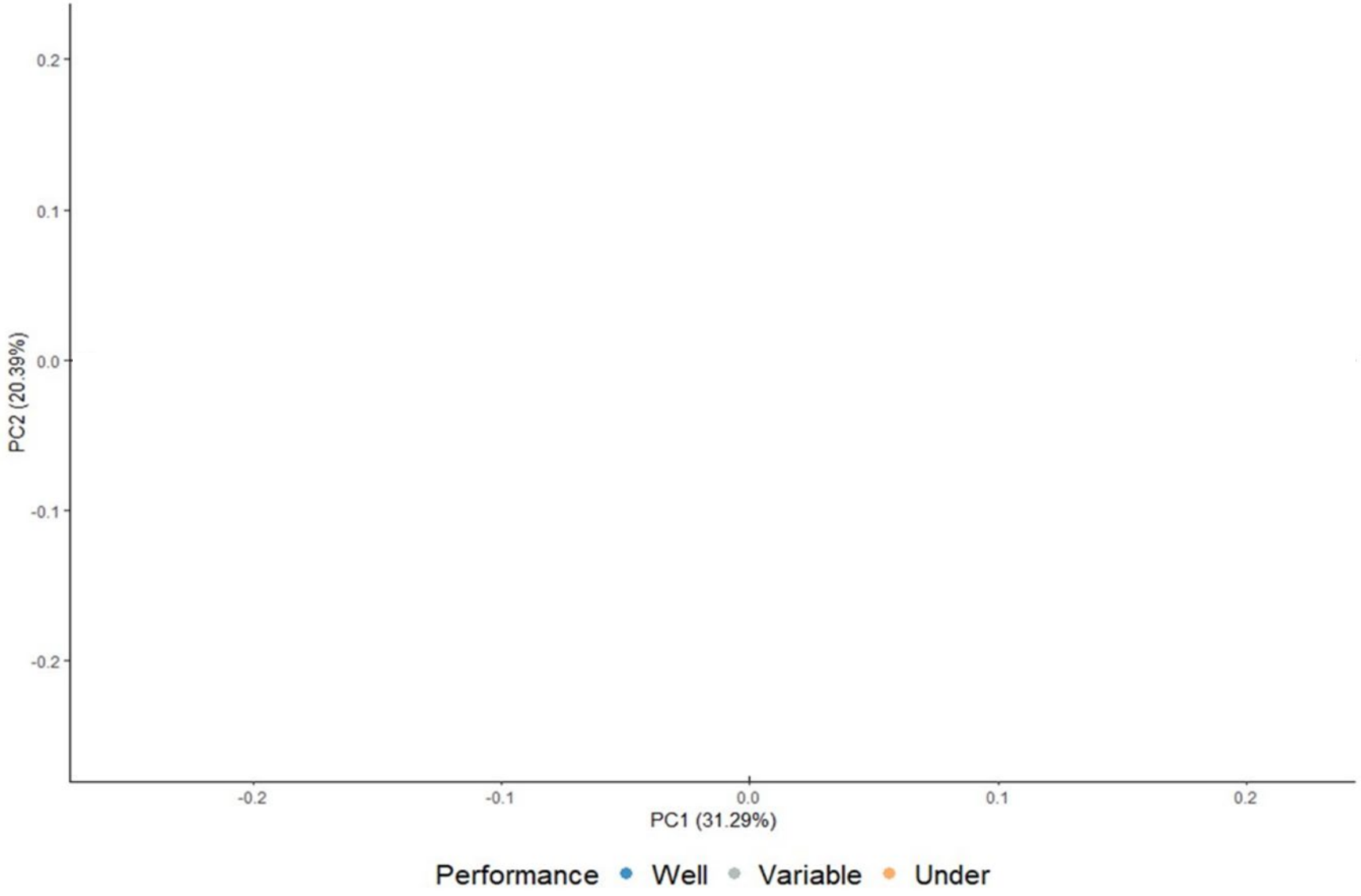
- Larger storages of…
  - MBP and residual P in well-performing compared to under-performing
  - Bicarbonate-Pi in variable-performing compared to well-performing
  - NaOH-extractable forms in under-performing

Average storages of phosphorus (P) forms as a % of total P

P Form	Well-performing	Variable-performing	Under-performing

Letters in parentheses represent Dunn's test results for multiple means comparisons of statistically significant Kruskal-Wallis test results (p-value ≤ 0.01)
Degrees of freedom = 2

Results: Distribution of Phosphorus Forms



Results: Mechanisms of P Storage

Cell 2 of STA-1E
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- The PCA alludes to four P storage mechanisms:
  1. Biotic storage mechanisms
     - Previously observed in EAV dominated STAs
     - Variable- and under-performing FWs
     - Associated with bicarbonate P, MBP, HCl-Po

Results: Mechanisms of P Storage (cont.)

- The PCA alludes to four P storage mechanisms:
  2. Abiotic $CaCO_3$-associated mechanism
     - Previously observed in SAV dominated STAs
       - Co-precipitation of phosphorus with $CaCO_3$
     - Well- and variable-performing systems
     - Associated with HCl-Pi, Ca, Mg, and residual P

SAV collected from Cell 3 of STA-2
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Results: Mechanisms of P Storage (cont.)

STA-5/6 FW1
(South Florida Water Management District)

- The PCA alludes to four P storage mechanisms:
  3. Abiotic Al/K-associated mechanism
     - Well-performing systems
     - Can occur alongside abiotic $CaCO_3$-associated mechanism or by itself
  4. Abiotic Fe-associated mechanism
     - Under-performing systems
     - Associated with NaOH-extractable P and Fe

Conclusions

- Well-performing FWs
  - Outflow TP concentrations < 19 μg L^{-1} and TP loads retained > 75%
  - Larger storages of MBP and residual P
  - Abiotic $CaCO_3$-associated and Al/K-associated storage mechanisms
- Variable-performing FWs
  - Outflow TP concentrations > 19 μg L^{-1} and TP loads retained > 75%
  - Larger storages of bicarbonate Pi
  - Biotic and abiotic $CaCO_3$-associated storage mechanisms
- Under-performing FWs
  - Outflow TP concentrations > 19 μg L^{-1} and TP loads retained < 75%
  - Larger storages of NaOH-extractable forms
  - Biotic and abiotic Fe-associated storage mechanisms

Conclusions (cont.)

Cell 2A of STA-3/4
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- Management implications
  - Vegetation
    - EAV/SAV mix with higher proportions of SAV
- Future research
  - Abiotic storage mechanisms associated with Al, Fe, and K
    - Different associations observed in different studies
      - Judy et al. (2021): Ca, K, and P
      - Julian et al. (2021): Al, Fe, and P
      - This study: (1) Al and K, (2) Fe and P
    - Fe-associated mechanism
      - pH destabilization at pH < 6.5?
        - Not characteristic of Everglades with a neutral pH
    - Are these FW specific mechanisms?
      - No two STA FWs are the same

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