LONG-TERM ACCRETION OF PHOSPHORUS IN THE EVERGLADES STORMWATER TREATMENT AREAS

March 15, 2013

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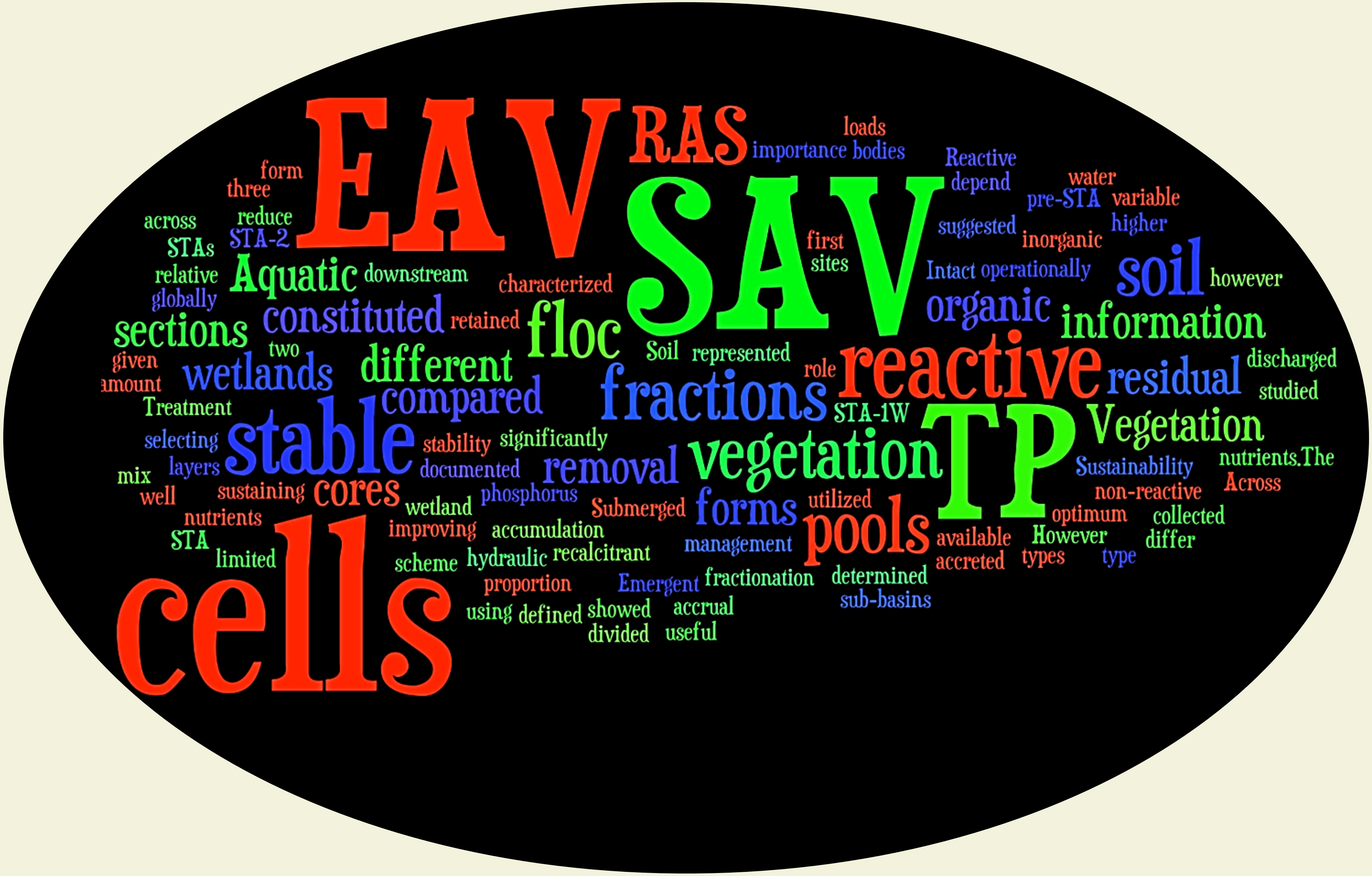
ABSTRACT


EAV
RAS
loads
importance bodies
form
three
Reactive
depend
water
variable
pre-STA
SAV
across
reduce
STA-2
STAs
first
sites
suggested
inorganic
higher
relative
Aquatic
downstream
characterized
Intact operationally
soil
however
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information
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two
Soil
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reactive
residual
discharged
given
amount
wetlands
different
studied
Treatment
compared
fractions
STA-1W
TP
Vegetation
selecting
stable
stability
significantly
layers
documented
removal
vegetation
Sustainability
nutrients.The
mix
well
sustaining
cores
phosphorus
Submerged
forms
utilized
non-reactive
Across
nutrients
wetland
optimum
collected
improving
accumulation
pools
STA
available
However
differ
limited
management
scheme
hydraulic
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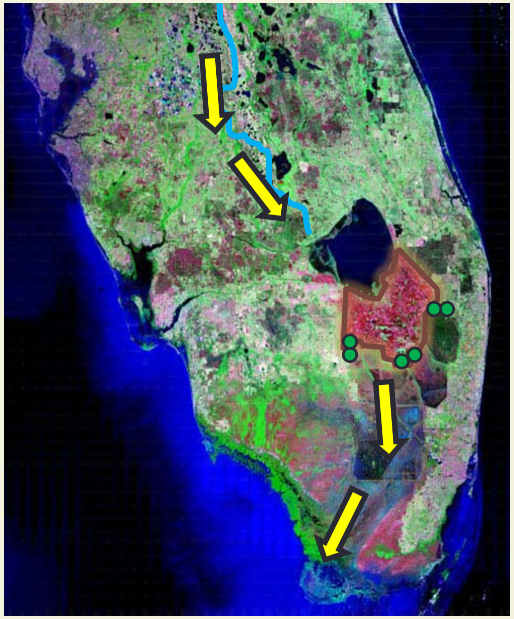
types
type
cells
proportion
Emergent
fractionation
determined
sub-basins
using
defined
showed
accrual
divided
useful

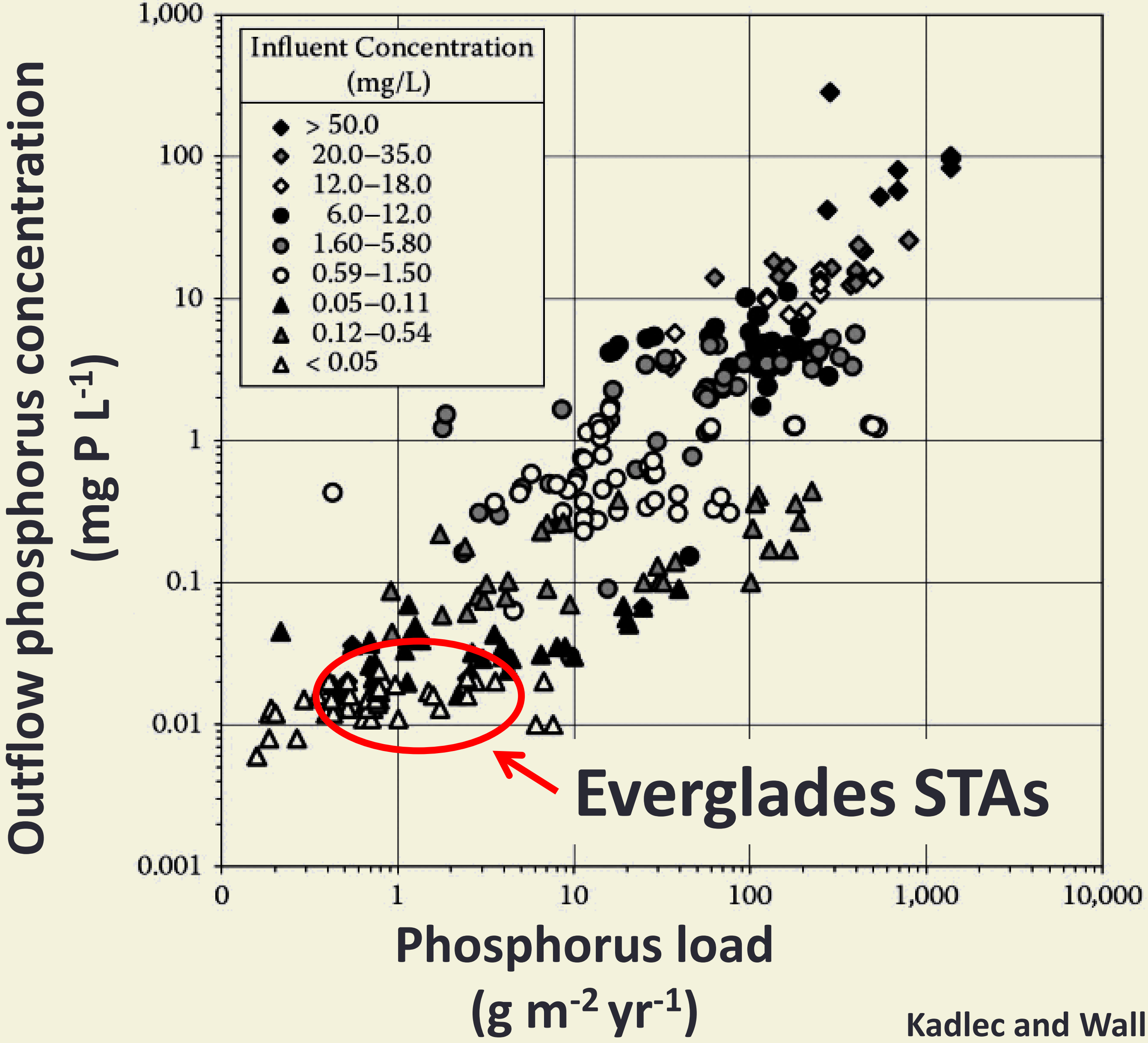
WATER QUALITY – THE EVERGLADES



The Everglades ecosystem

- Historically oligotrophic system
- Excess nutrient (phosphorus) inputs
- Trophic structure changes
- The South Florida Water Management District (SFWMD) constructed ~18,000 ha of Stormwater Treatment Areas (STAs)
- First STA came online – 1994, total six STAs till date
- STAs removed ~ 1,500 metric tons of phosphorus
- Long-term sustainability of STAs is very important

NORTH AMERICAN CONSTRUCTED WETLANDS



Everglades STAs

Kadlec and Wallace, 2009; p. 376

WETLAND PROCESSES

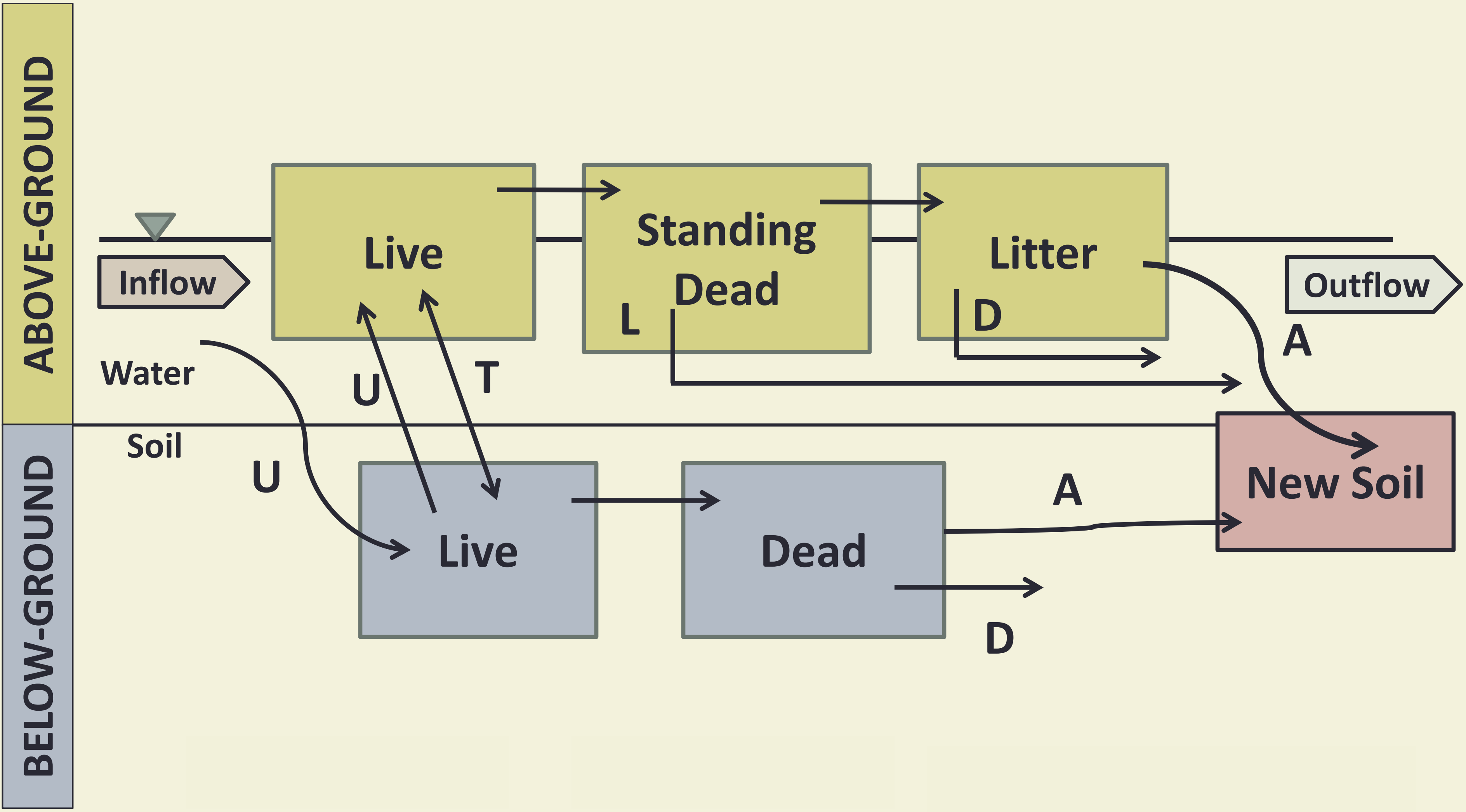
Two aspects of P removal processes in STAs

- Retention – sedimentation, co-precipitation and biological uptake
- Accretion – steady accumulation organic matter – Recently Accreted Soil
- Management goals
    - Short term
    - Long term

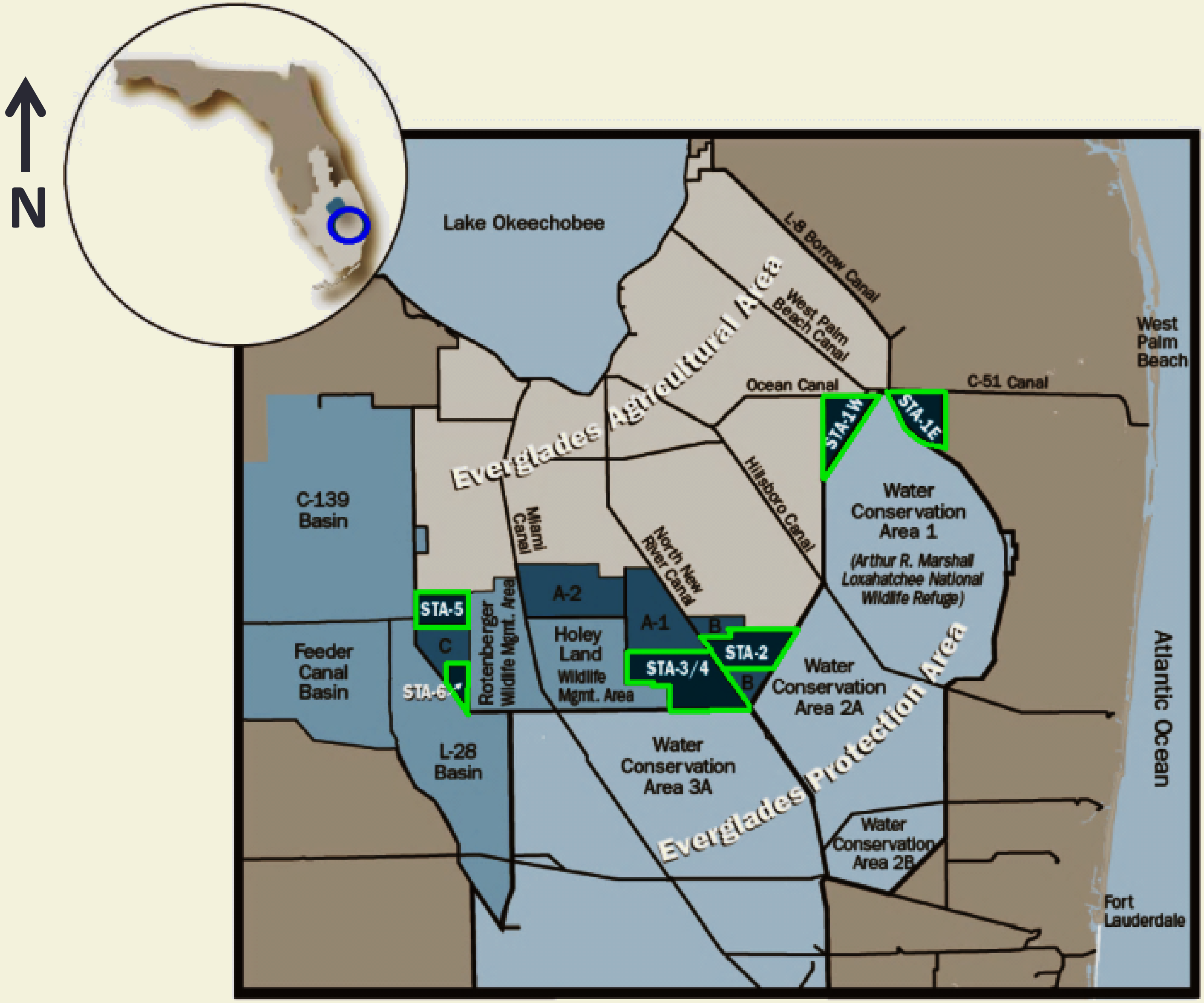
Meet operational envelope targets

Long-term sustainability of STAs!

WETLAND PROCESSES

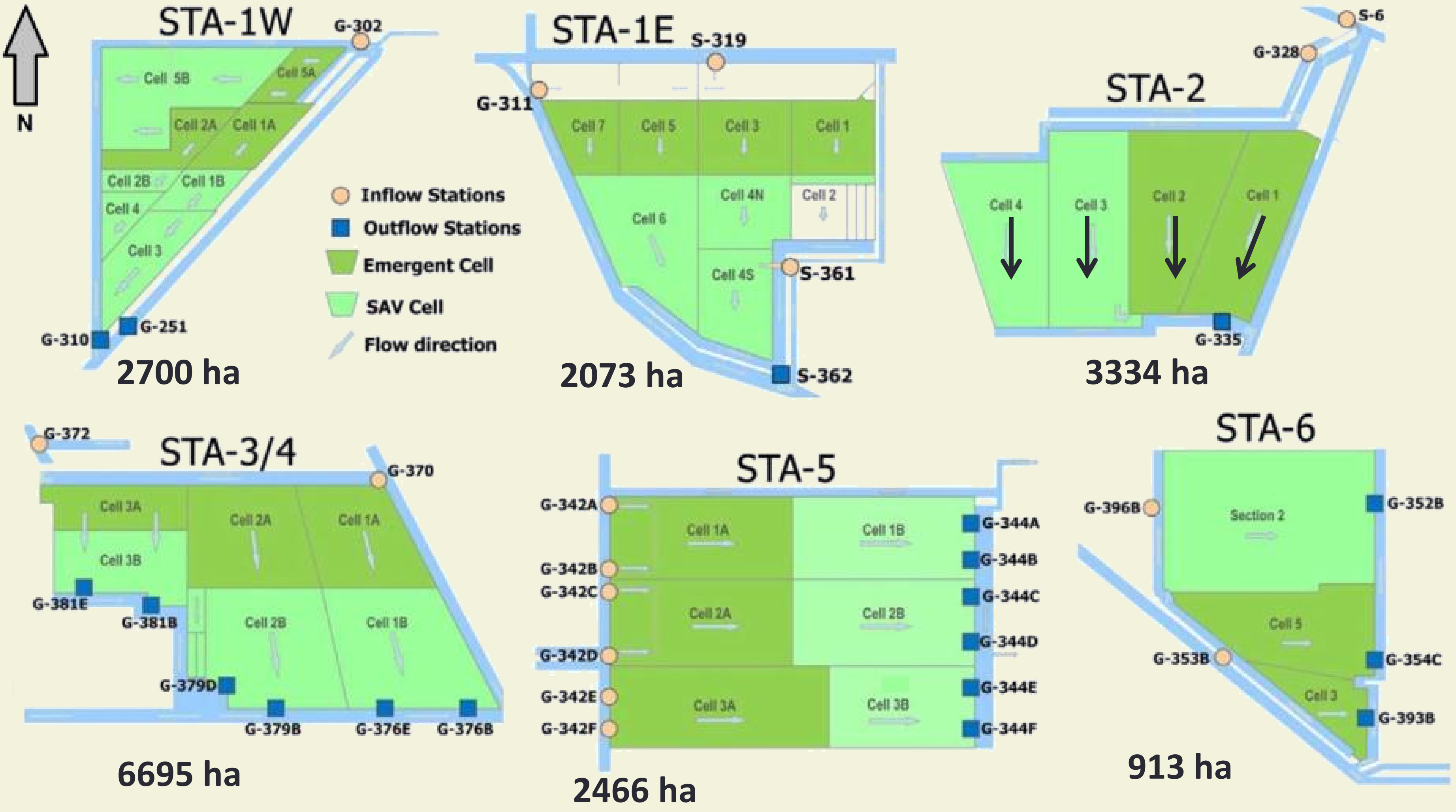


EVERGLADES STORMWATER TREATMENT AREAS



Source*:* **South Florida Water Management District**

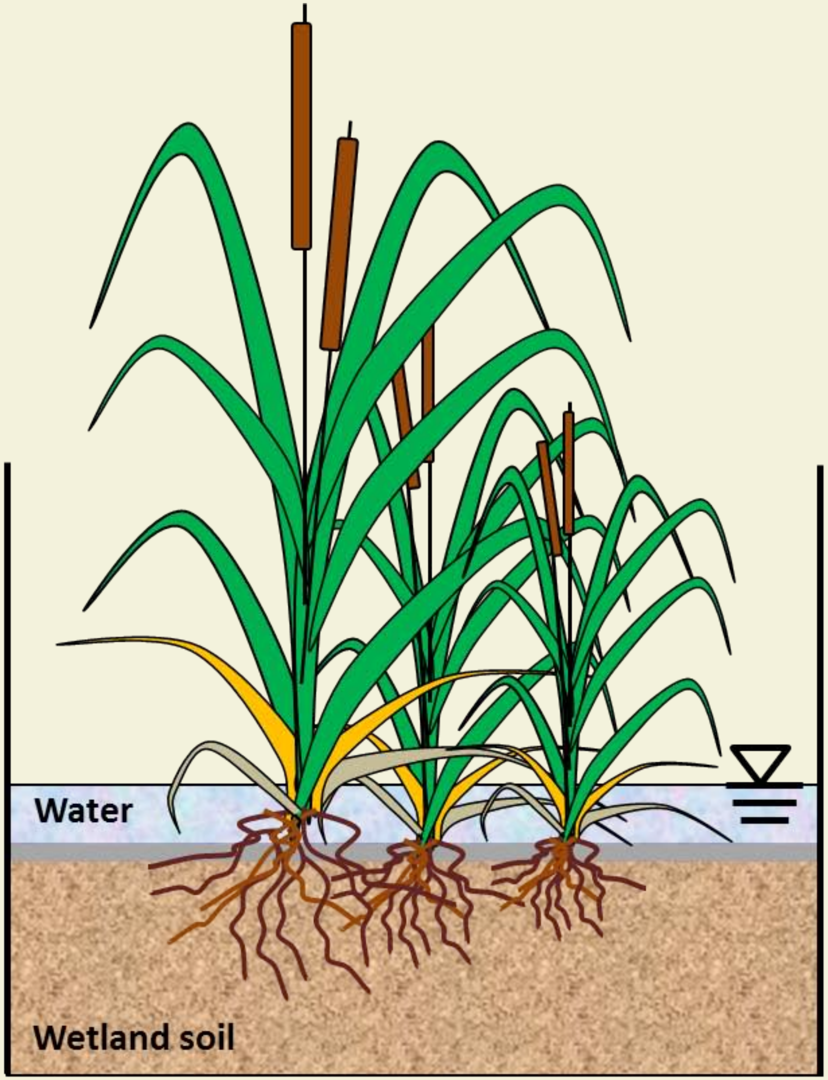
STAs CONFIGURATION AND TREATMENT CELLS



Schematics not to scale

Source*:* South Florida Water Management District

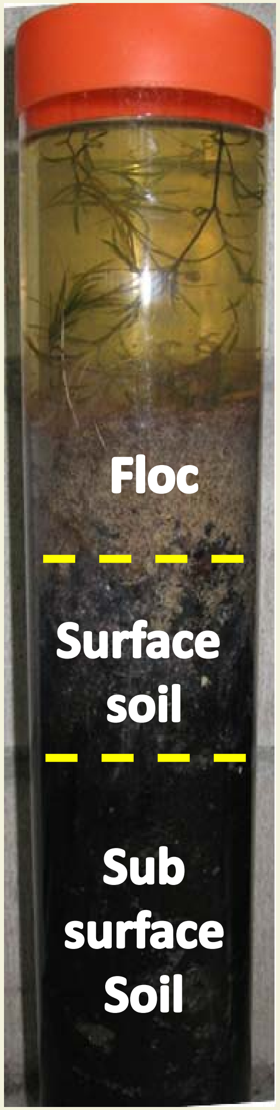
STA VEGETATION



Emergent Aquatic Vegetation (EAV)

WHY SOILS?

- Soils are integrators of long-term water chemistry conditions
- Nutrient inputs to wetlands (specifically phosphorus) primarily stored in soil
- Nutrient concentration in soils play a big role in outflow water quality
- Spatio - temporal gradients of soil nutrients are used to assess long-term nutrient impacts
- Soil biogeochemical properties are indicators of ecosystem conditions



OVERALL OBJECTIVE

Understand wetland biogeochemical processes that regulate P removal efficiency and dictate long-term stabilization of removed P

- Hypothesis – Hydraulic loading, nutrient inputs, and wetland vegetation regulate P removal efficiency and control long-term sustainability of STAs

BACKGROUND

- Available datasets on STAs (soil, water quality) were reviewed
- Phosphorus retained from water column (P_{wc}) caused enrichment of surface soil
- No clear relationship between P_{wc} and P stored in floc and soil
- Preliminary P mass balance was developed to understand P distribution in soil profile
- Inverse relationship between STA age and P stored in floc and soil

OBJECTIVE- 1

Determine soil accretion rates in wetlands and explore influence of STA age on accretion rates

- Utilize stratigraphic characteristics of soil profile to identify depth of recently accreted soil (RAS)
- Hypothesis –Accumulating matter conserves the attributes of prevailing conditions (nutrient loading and vegetation) in wetlands

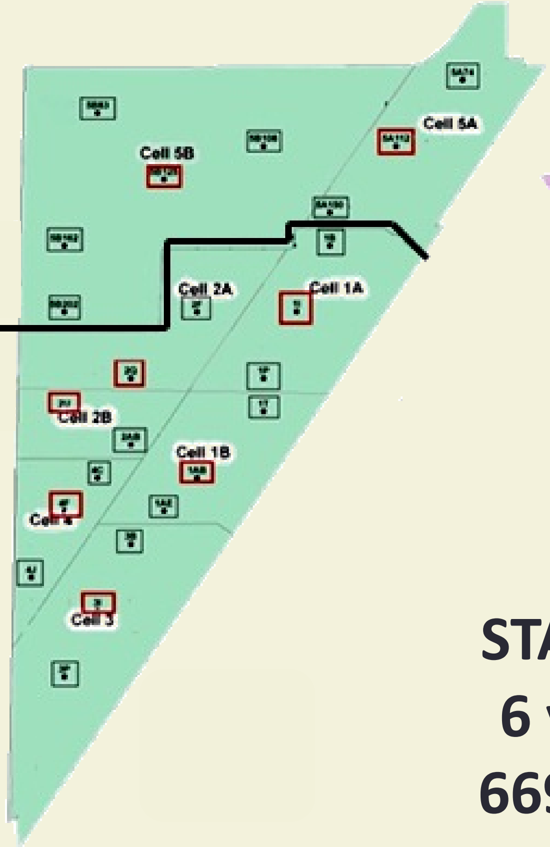
  - As STAs age, rate of soil and P accretion slow down, resulting in higher outflow concentration

SAMPLING SITES

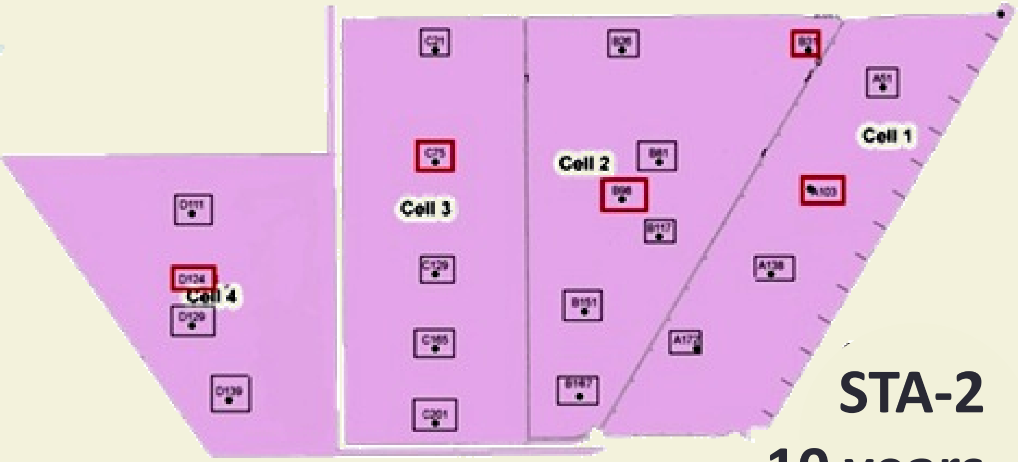
N

10 years

16 years

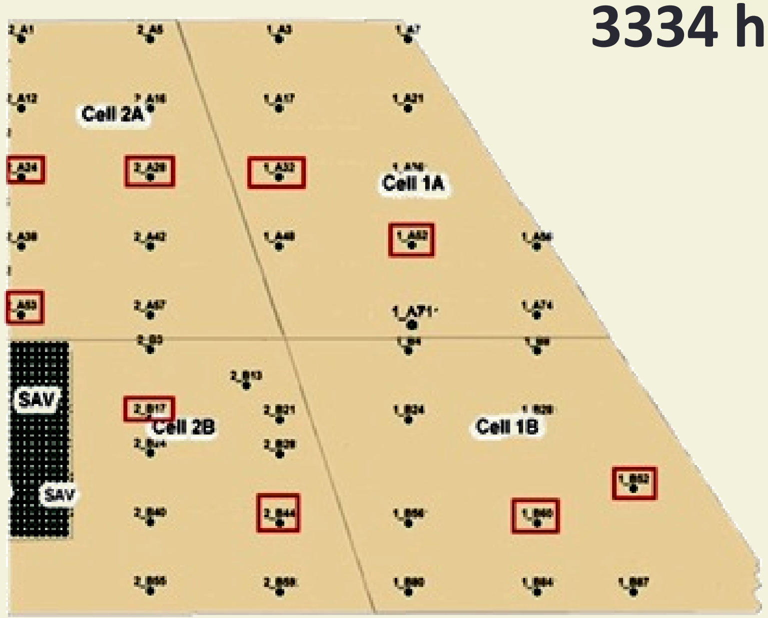


STA-1W
2700 ha



STA-2
10 years
3334 ha

STA-3/4
6 years
6695 ha



STA	Soil cores
STA-1W	40
STA-2	29
STA-3/4	58

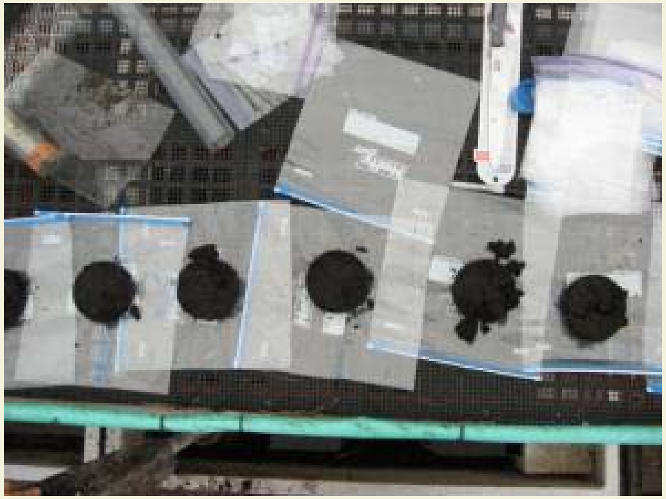
Base map source: South Florida Water Management District

METHODS

- Intact soil cores (n=128) between 10-40 cm depth collected using steel tube (10.2 cm internal diameter) and sectioned at 2 cm depth intervals
- Samples analyzed for physico-chemical properties (bulk-density, total P, total carbon, total nitrogen and isotopic ratios of N and C)
- Identification of change point depth using SegReg software and soil parameters
- Accretion rate determined using operational age of STAs

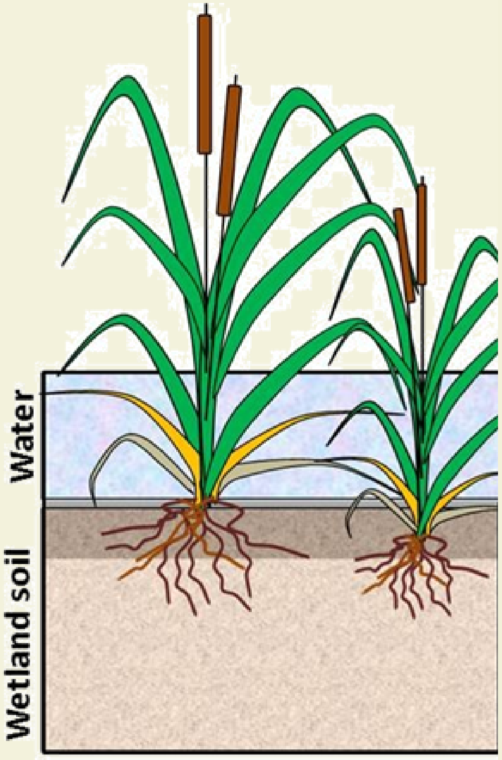
SAMPLING

SAMPLE PROCESSING



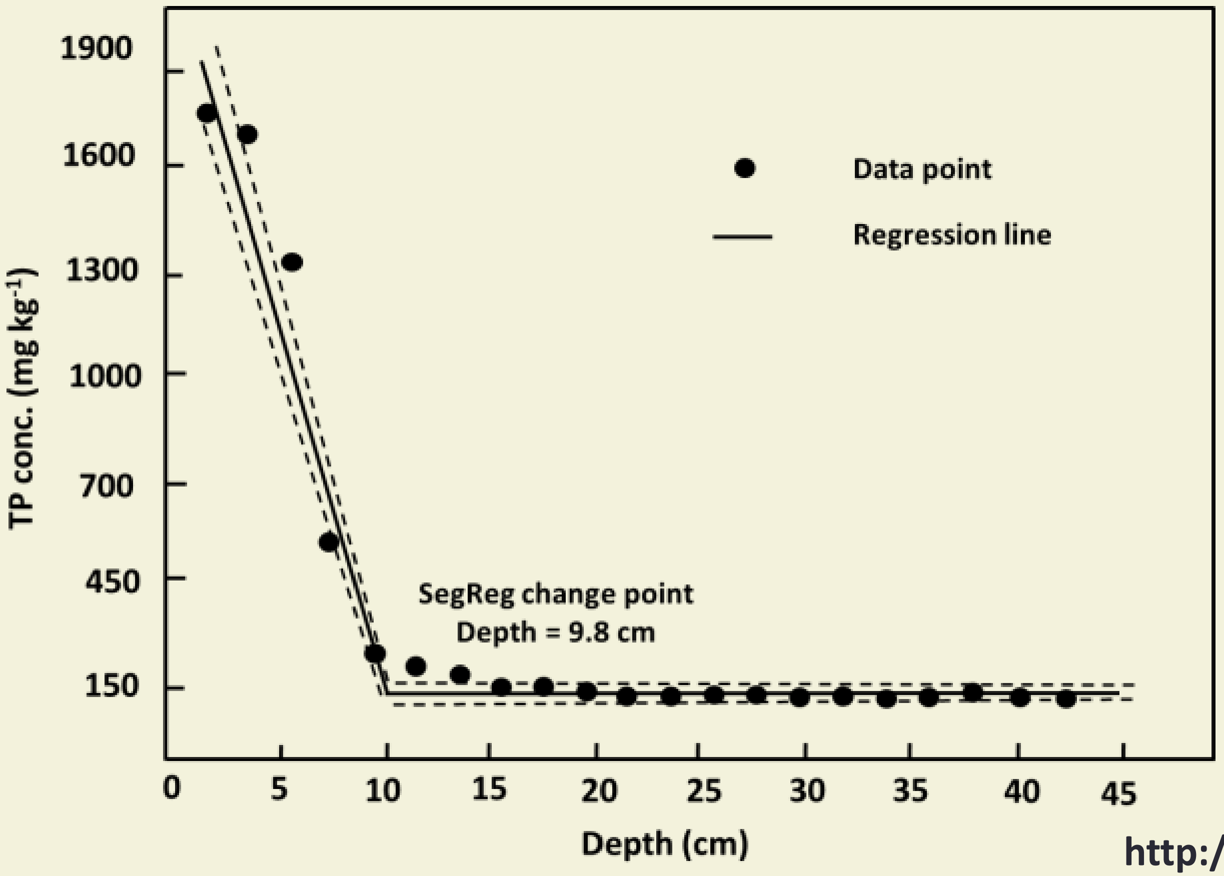
CHANGE POINT DETERMINATION

- Change point depth as boundary between recently accreted soil and pre-STA soil (native soil)



CHANGE POINT DETERMINATION

- Software program SegReg was used for identifying change points with 90% confidence interval
- Segmented linear regression using soil profile parameters



$$y_i = ax_i + b + \epsilon$$

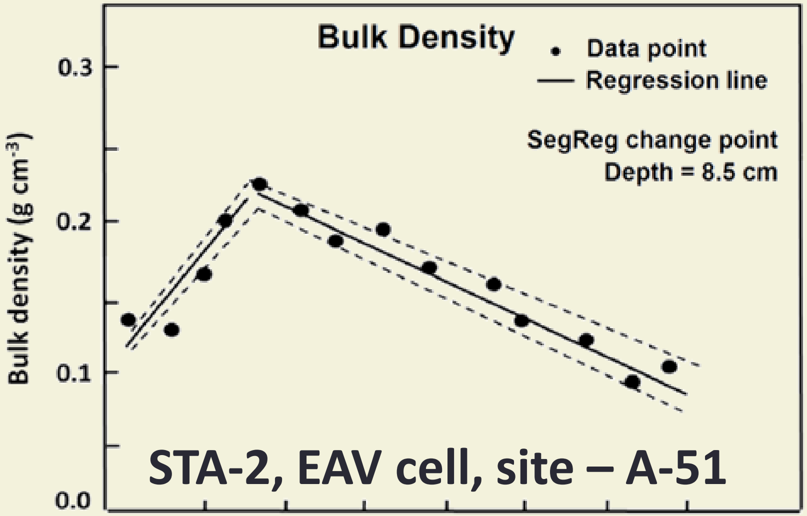
X_i< Change point

$$y_j = cx_j + d + \epsilon$$

X_j> Change point

http://www.waterlog.info/segreg.htm

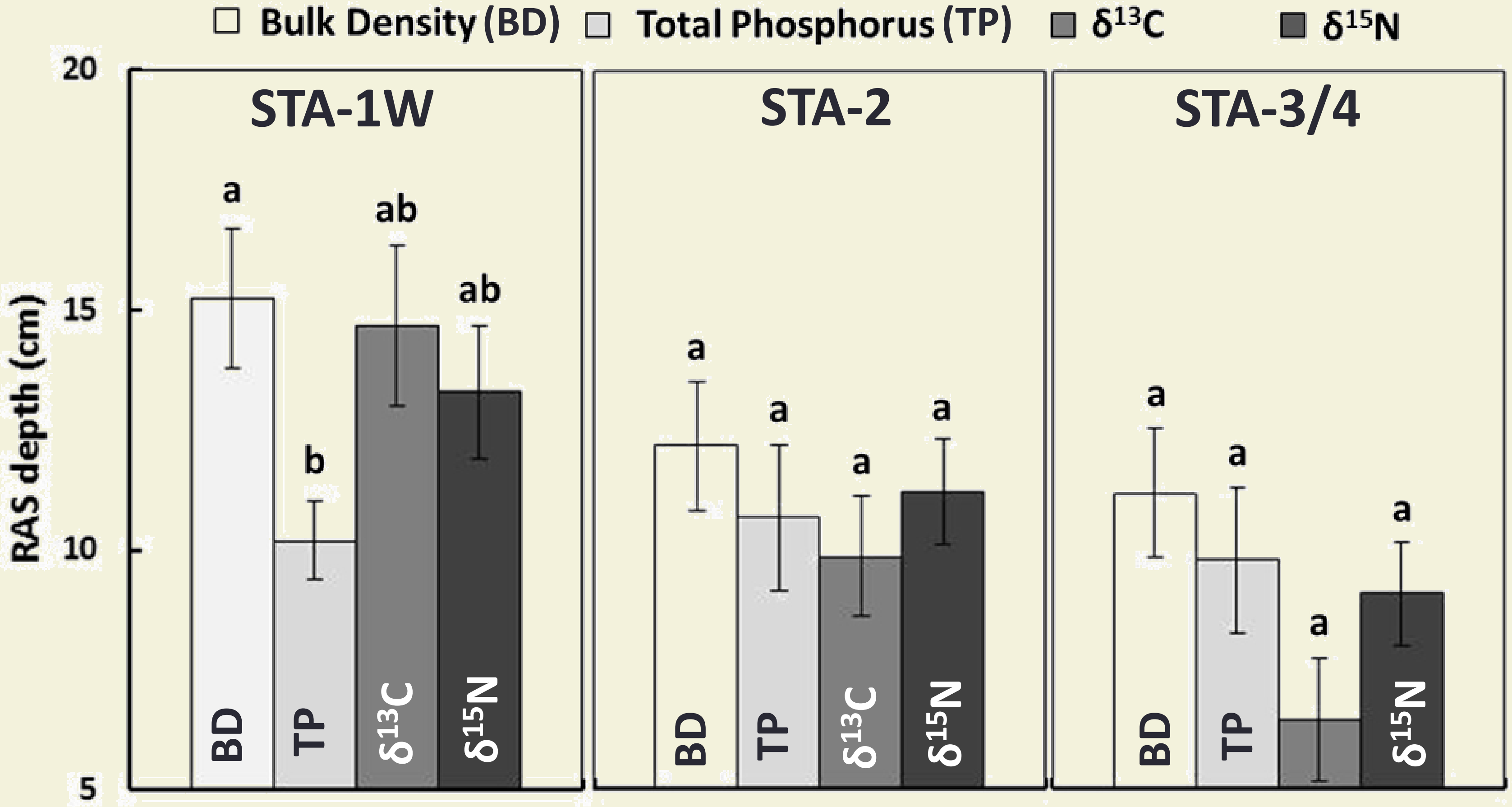
SegReg OUTPUT



STA-2, EAV cell, site – A-51

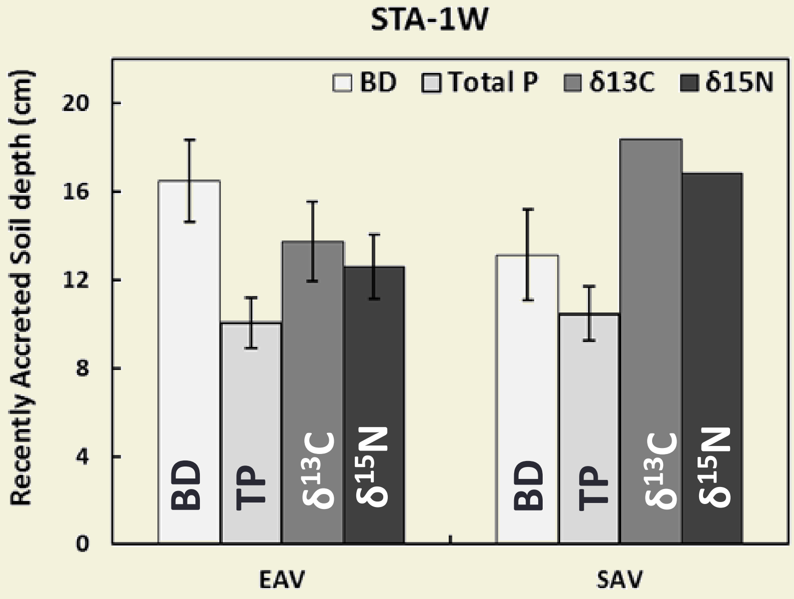
RECENTLY ACCRETED SOIL DEPTH

- No significant difference between RAS depths in each STA when tested separately (Tukey-Kramer HSD test, $p<0.05$)



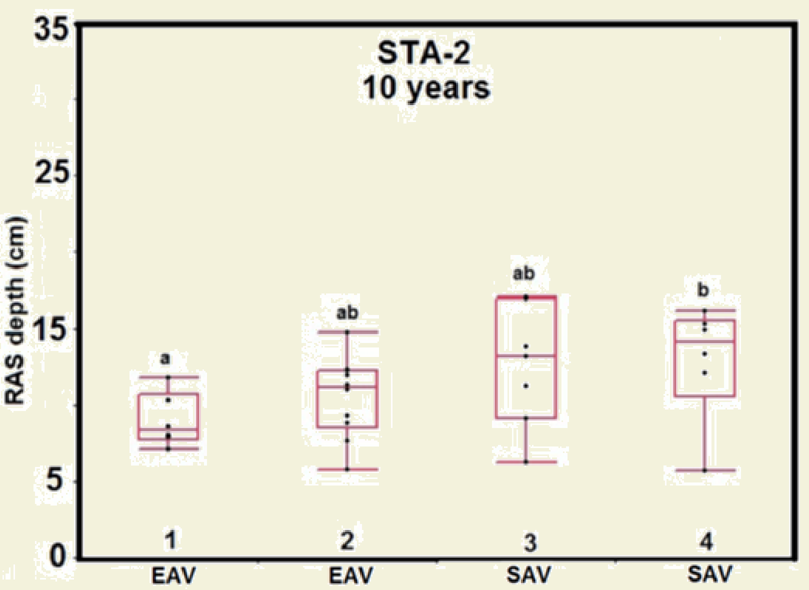
RECENTLY ACCRETED SOIL DEPTH

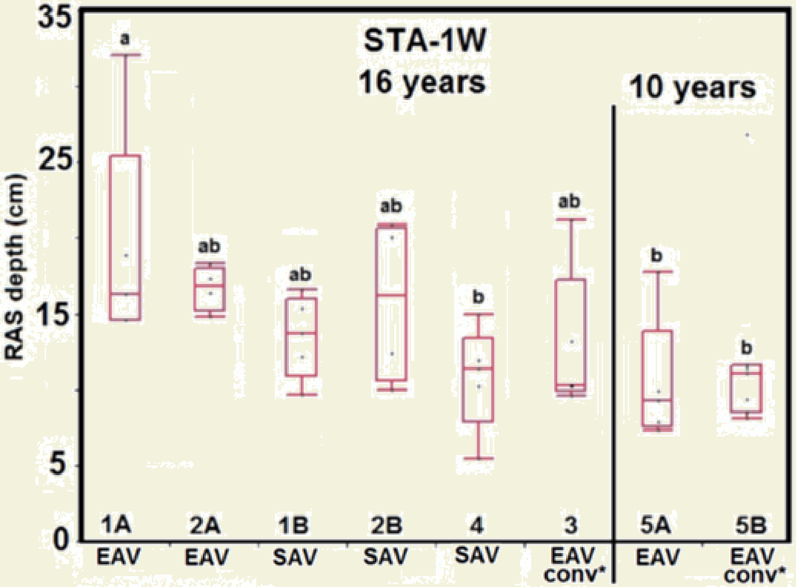
- No significant vegetation difference on RAS depths as determined by four key parameters in each STA (Tukey-Kramer HSD test, $p<0.05$)

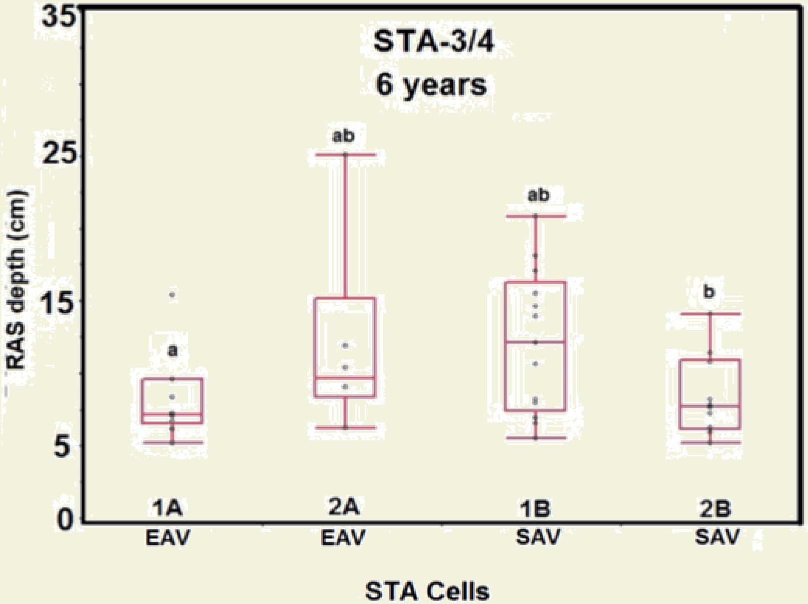


RECENTLY ACCRETED SOIL DEPTH

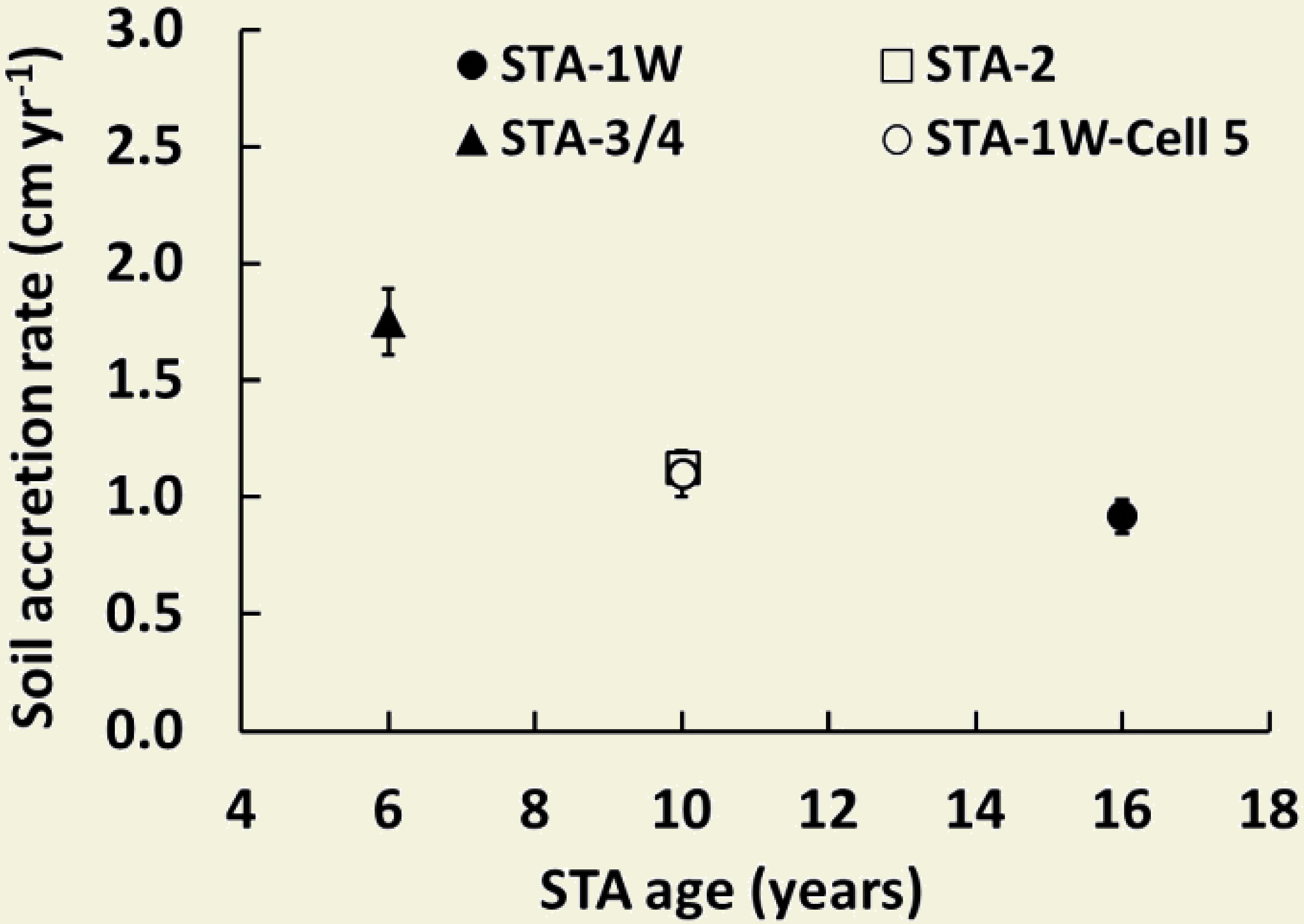
- Mean RAS depths in STA cells with variable vegetation (Tukey -Kramer HSD test, $p<0.05$)
- Avg. RAS depth for STA-1W, STA-2 and STA-3/4 was 15 ± 5, 11 ± 3 and 10 ± 4 cm



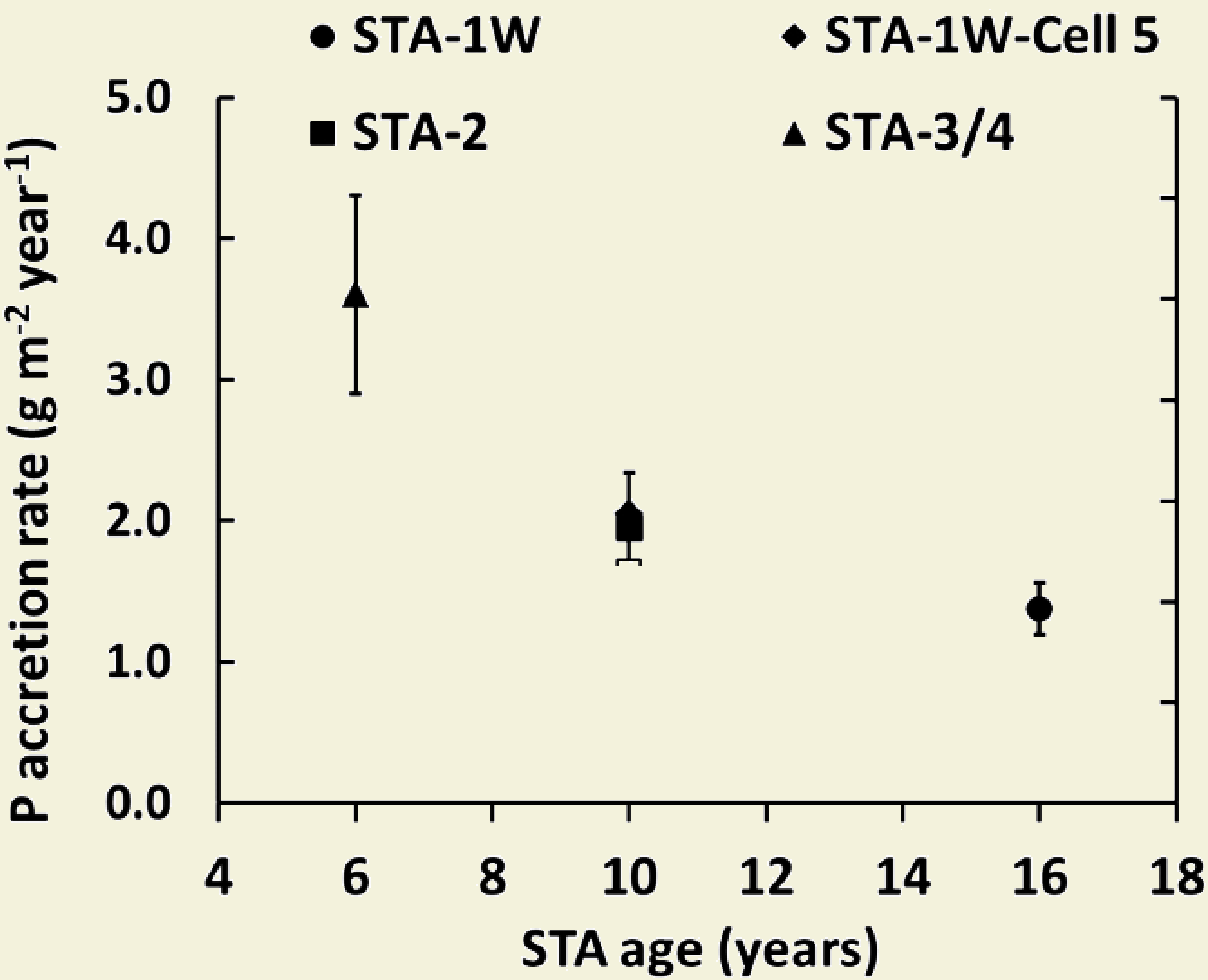




SOIL ACCRETION RATES AND STA AGE



PHOSPHORUS ACCRETION RATE AND STA AGE



CONCLUSIONS AND IMPLICATIONS

- Mean RAS depth ranged 10 – 15 cm
- Soil accretion rate in STAs - 1.0 – 1.7 cm yr^{-1} [within the range measured in other wetland system – 0.1-2.4 cm yr^{-1}]
- Phosphorus accretion rate for these STAs ranged from 1.3 - 3.0 g P m^{-2} yr^{-1}
- Soil and phosphorus accretion rates showed decline over time and impacted outflow water quality
- Hydraulic conditions of STAs play key role in continued accretion

OBJECTIVE- 2

Perform P mass balance in select STAs using soil P storages and water chemistry data

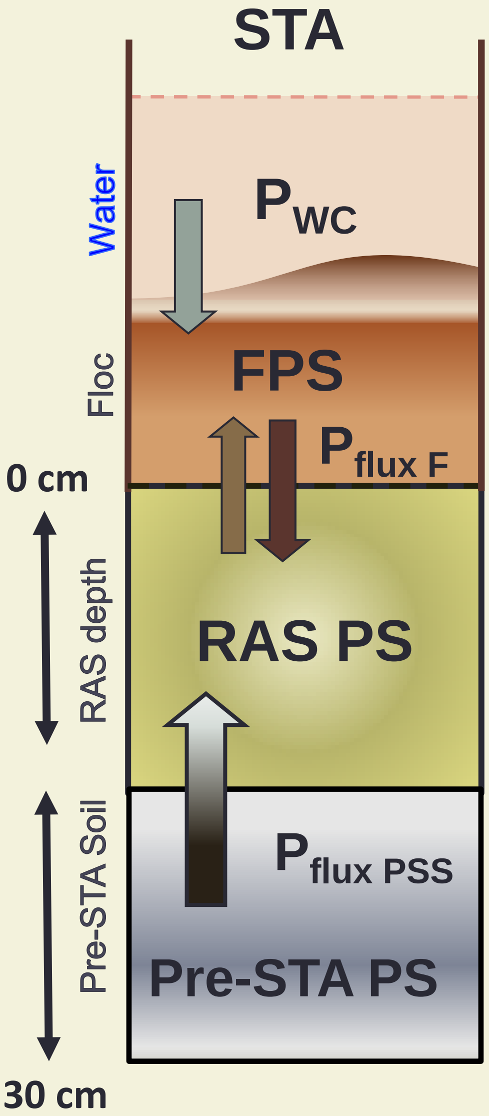
- Hypothesis – Internal re-distribution of P within RAS and pre-STA soils is mediated by vegetation and potentially regulates surface water quality

METHODS

- Phosphorus storages (g P m^{-2}) in floc, RAS and pre-STA soils were calculated for STAs -1W, 2 and 3/4
- Mass of P for RAS and pre-STA portion was obtained for every 2 cm soil section and adding them up for whole portion
- Maximum soil depth considered for mass balance was 30 cm
- Soil sampling was conducted in WY2010, so P_{wc} was obtained for POR

METHODS

Phosphorus mass balance for select STAs



All values expressed in g P m^{-2}

P_{WC}= P retained from water column [Inflow – Outflow]

FPS = Floc P storage [WY2010]

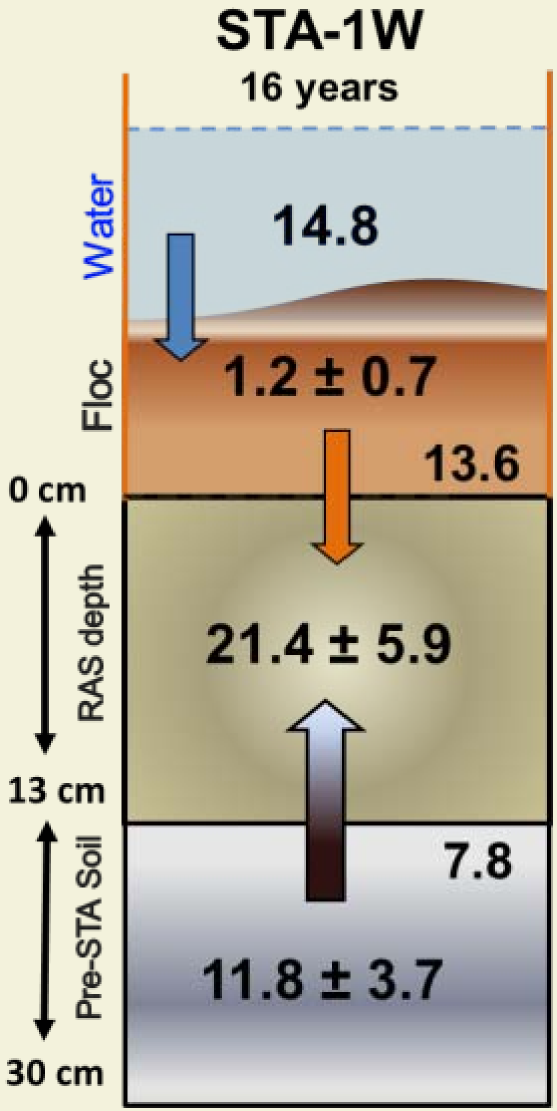
$P_{flux\ F}$ = P flux (Floc and RAS) [$P_{flux\ F}$ = FPS – Wc]

RAS PS= Recently Accreted Soil P storage [WY2010]

$P_{flux\ PSS}$ = P flux (RAS and Pre-STA soil) [$P_{flux\ PSS}$ = RAS PS – $P_{flux\ F}$]

Pre-STA PS = Pre-STA soil P storage

PHOSPHORUS MASS BALANCE



All values expressed in g P m^{-2}

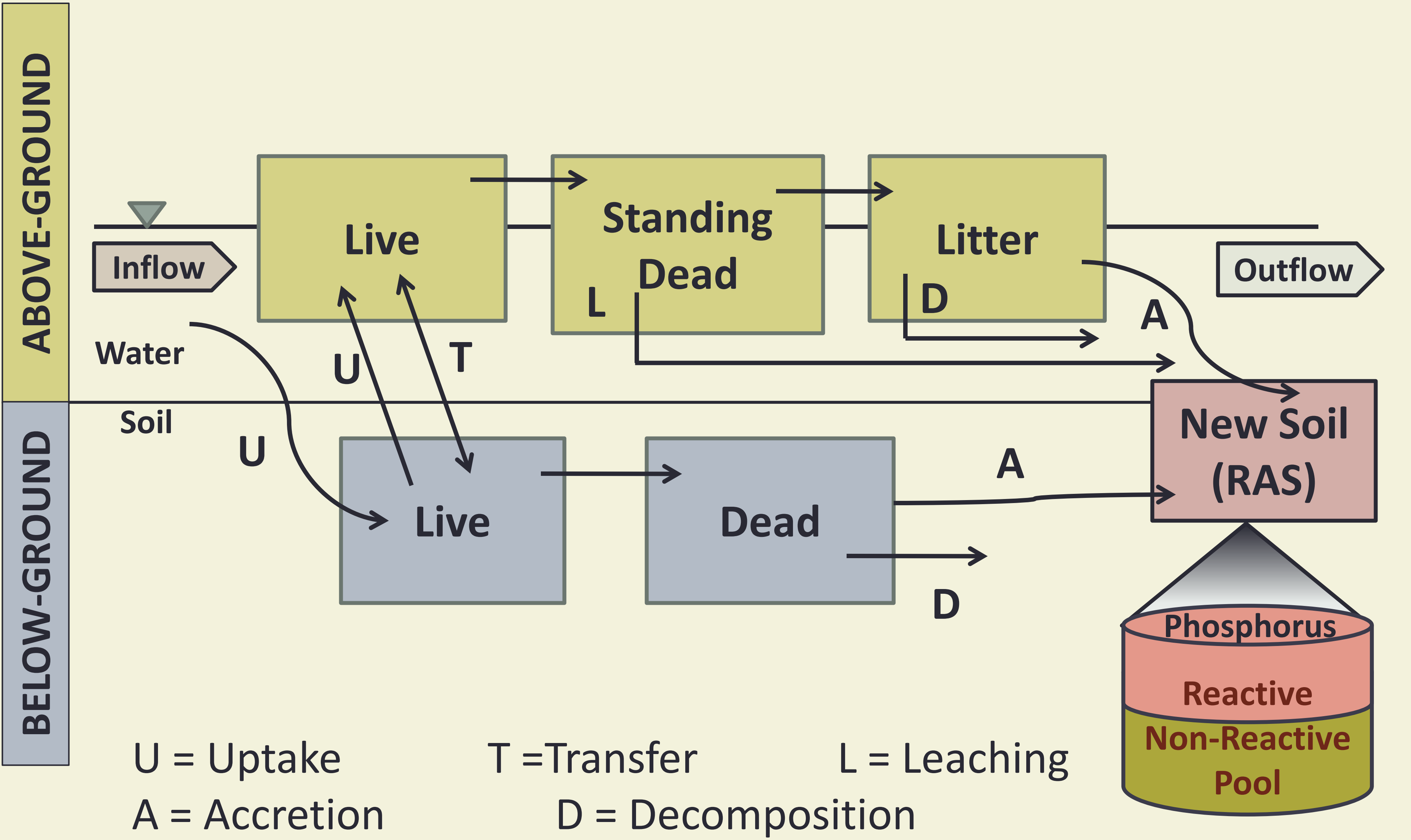
CONCLUSIONS AND IMPLICATIONS

- All three STAs showed P flux from pre-STA soils to RAS
- Highest $P_{flux\ PSS}$ in STA-3/4, in operation for 7 years and had low POR P_{WC}
- High $P_{flux\ PSS}$ suggests role of vegetation in mining subsurface P and deposition on surface through detrital accumulation
- Redistribution of P within soil layers could have implications on long-term stability of P

OBJECTIVE-3

- Assess influence of wetland vegetation (EAV vs SAV) on stability of accreted P
  - Determine proportion of reactive and stable P for two vegetation types (EAV and SAV)
  - Examine long-term sustainability of STAs by exploring stability of accreted P in floc and RAS
  - Hypothesis – Different vegetation types influence P forms in RAS and potentially mobile forms could undermine long-term sustainability of STAs

WETLAND PROCESSES

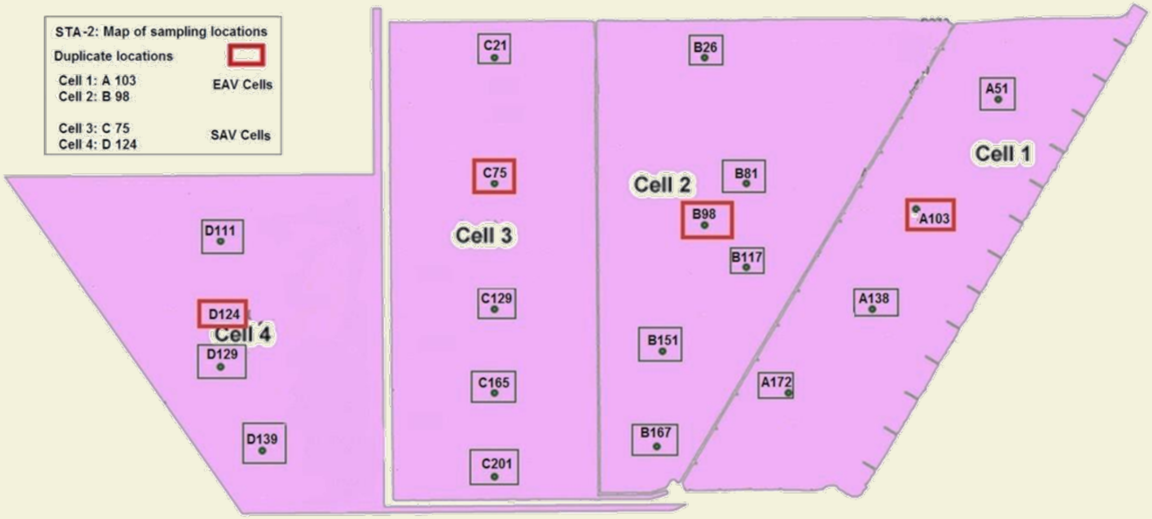


U = Uptake
T =Transfer
L = Leaching
A = Accretion
D = Decomposition

SITE DESCRIPTION

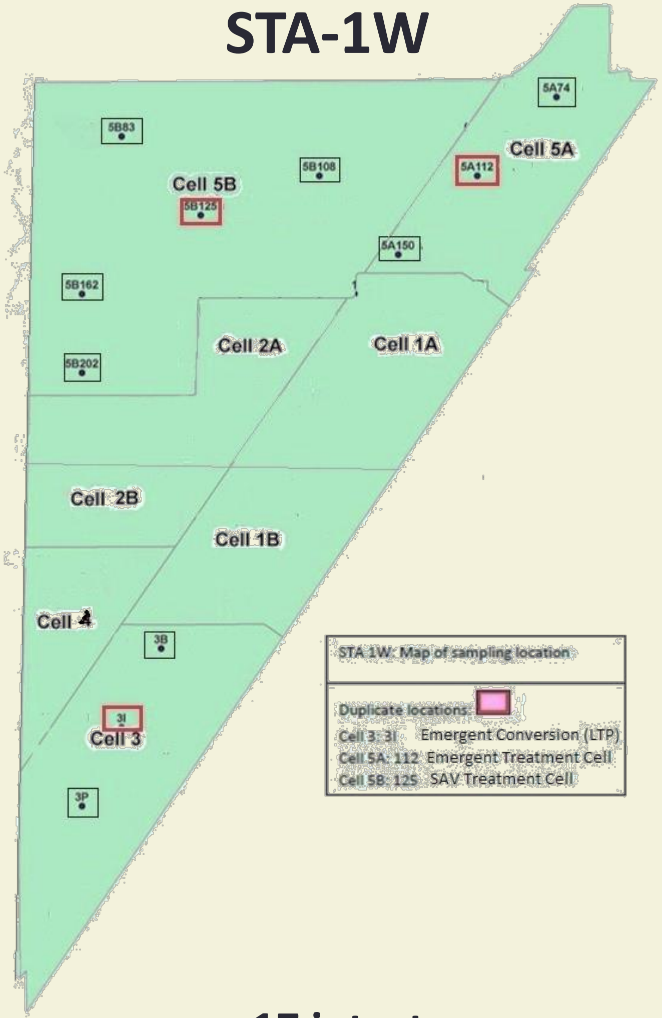
N

STA-2



27 intact cores
All 4 cells

STA-1W



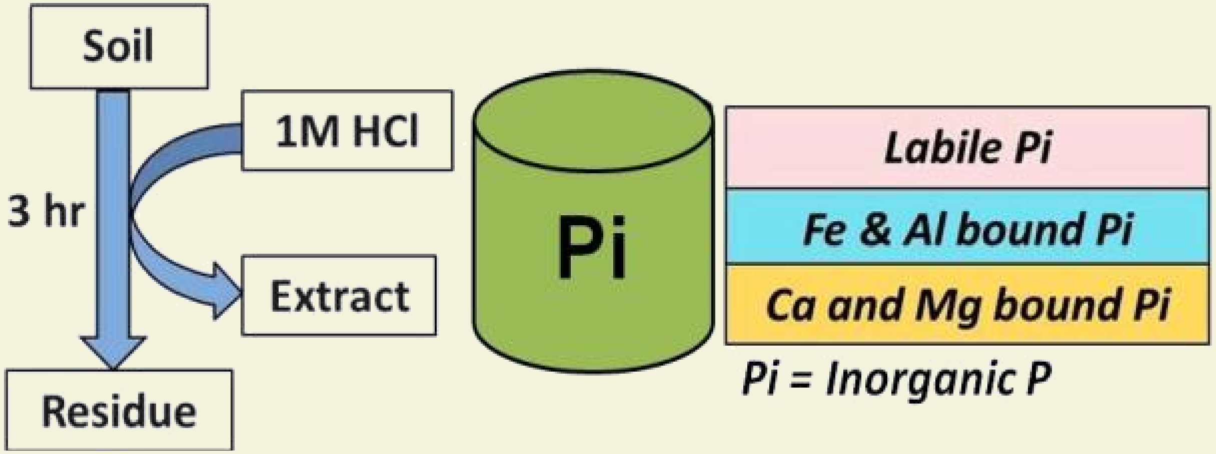
17 intact cores
Cells 5A, 5B and 3

Base map source: South Florida Water Management District

METHODS

- Intact soil cores from STA-1W and STA-2 (n=44)
- Soil cores separated into floc, RAS and pre-STA
- Moisture content, bulk density, total nutrients (P, C and N) were determined
- Inorganic (Pi), Organic (Po), and residual P pools were measured
- Inorganic fraction analyzed for total metals (Ca, Mg, Fe and Al)
- All comparisons were carried out using student’s t-test assuming equal variances ($p<0.05$)

FRACTIONATION SCHEME



Soil

1M HCl

3 hr

Extract

Residue

Pi

Labile Pi

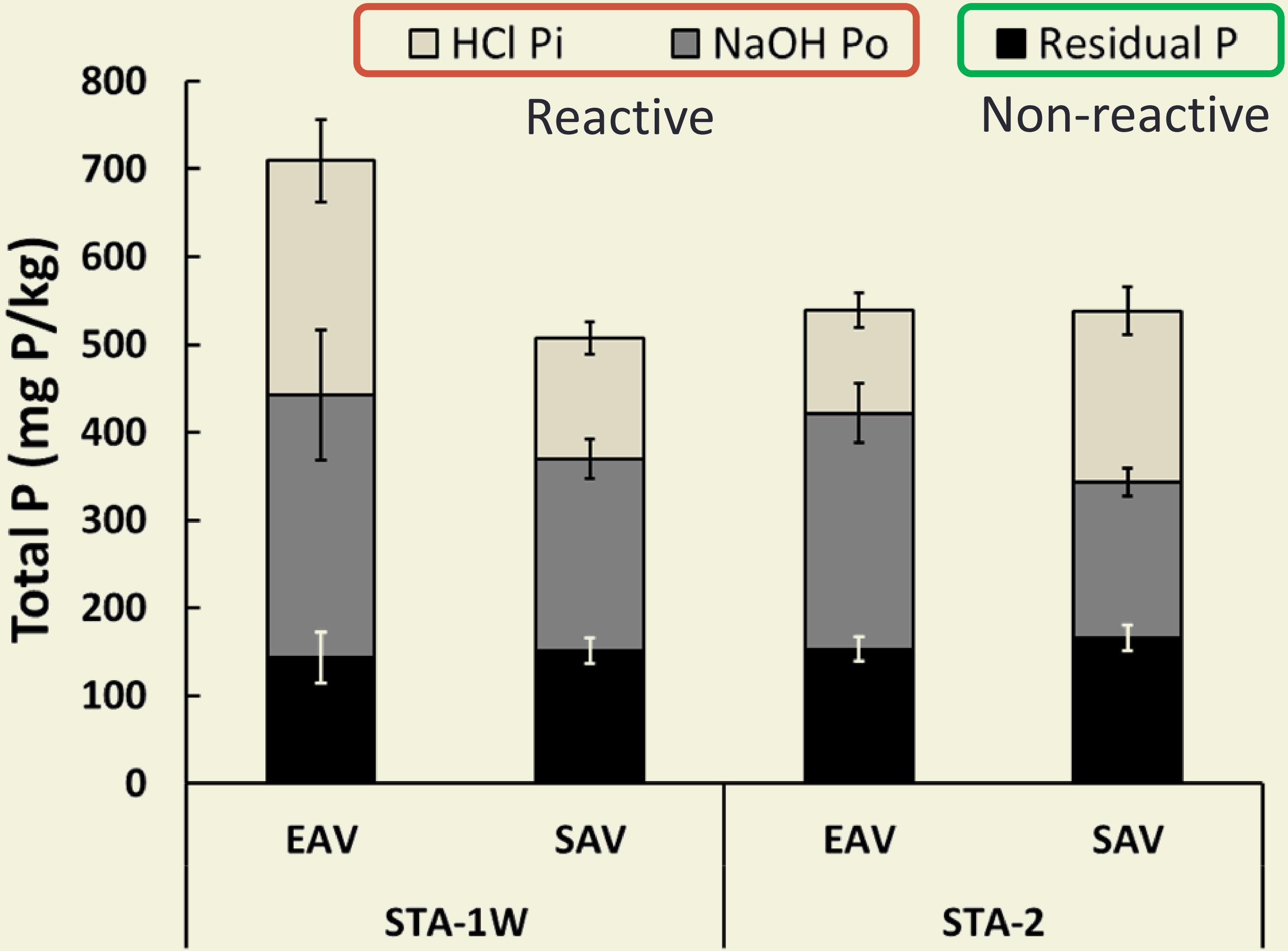
Fe & Al bound Pi

Ca and Mg bound Pi

Pi = Inorganic P

Modified from- Ivanoff *et al.*, 1998

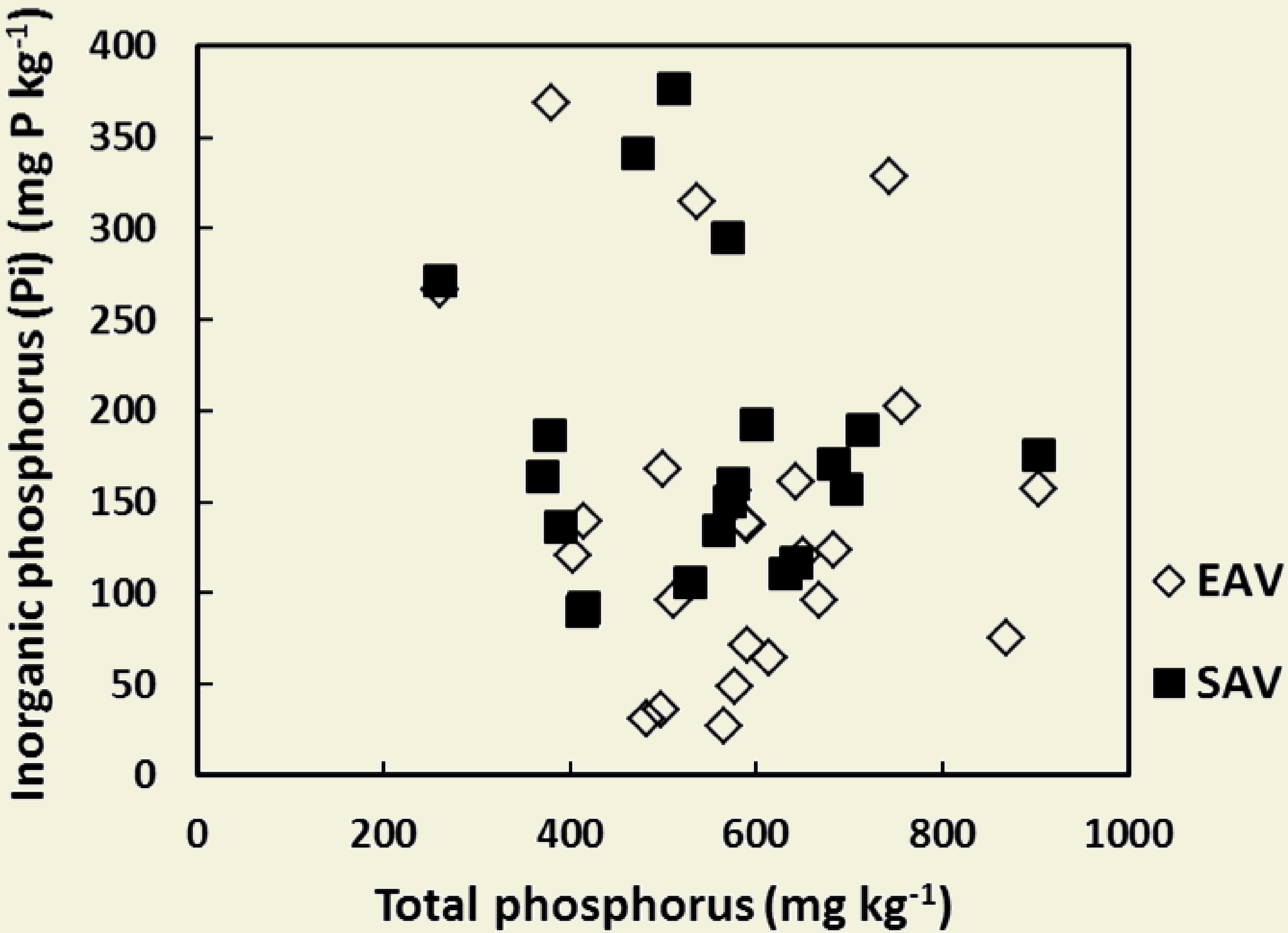
FRACTIONATION RESULTS



Error bars represent standard error of the mean

FRACTIONATION RESULTS

- Inorganic P pools as a fraction of total P in EAV and SAV (Both STAs combined)



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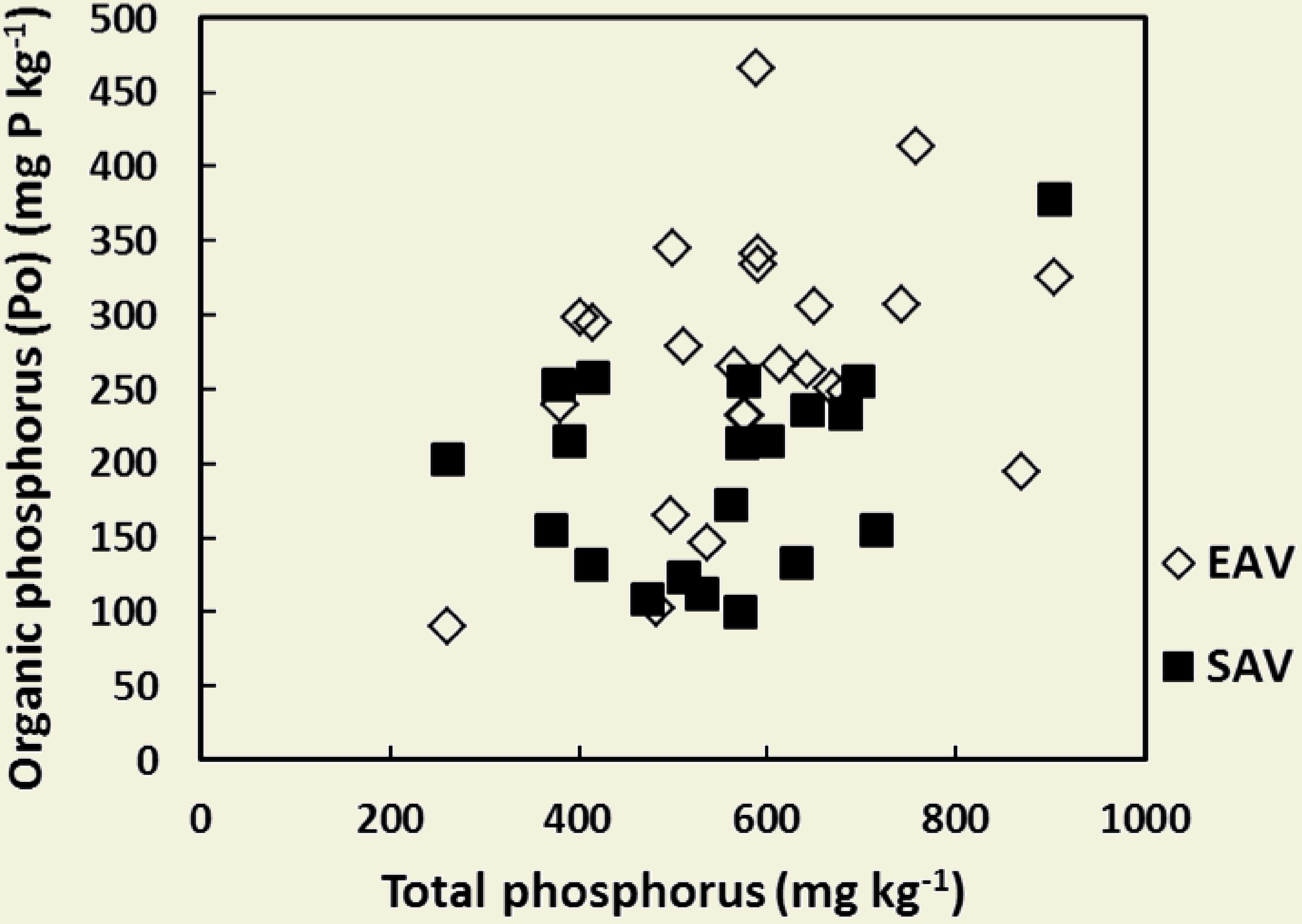
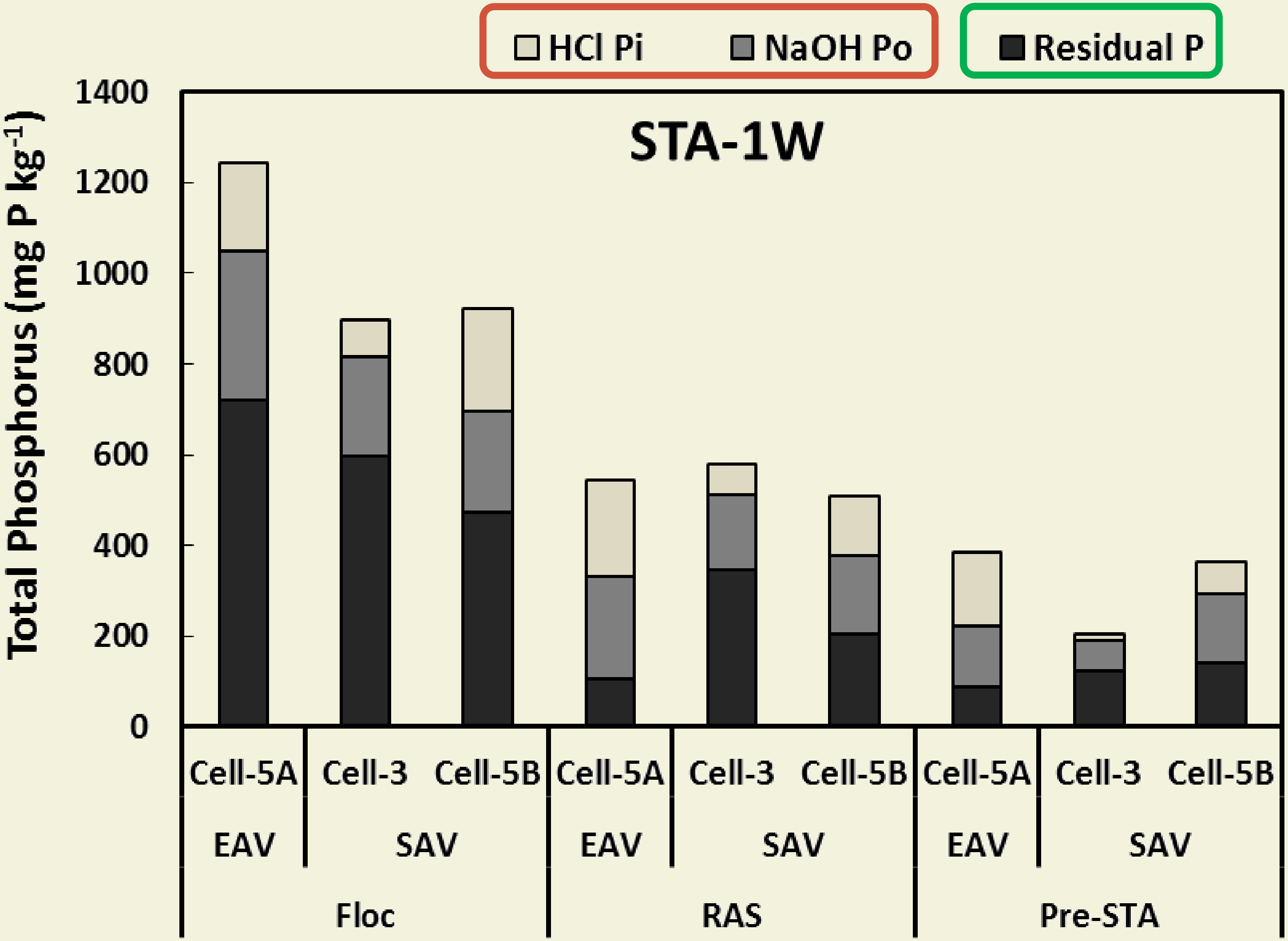
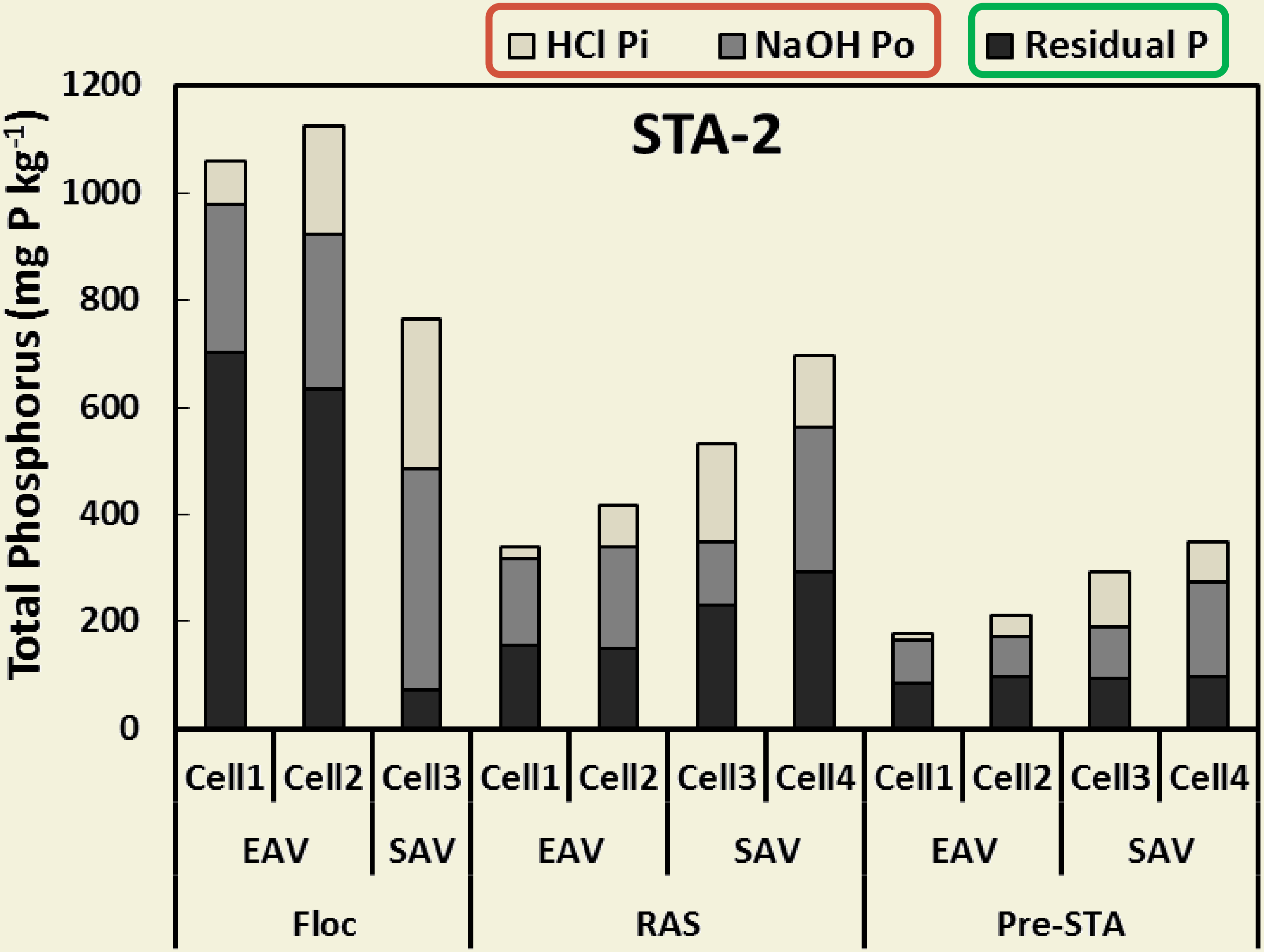


FRACTIONATION RESULTS

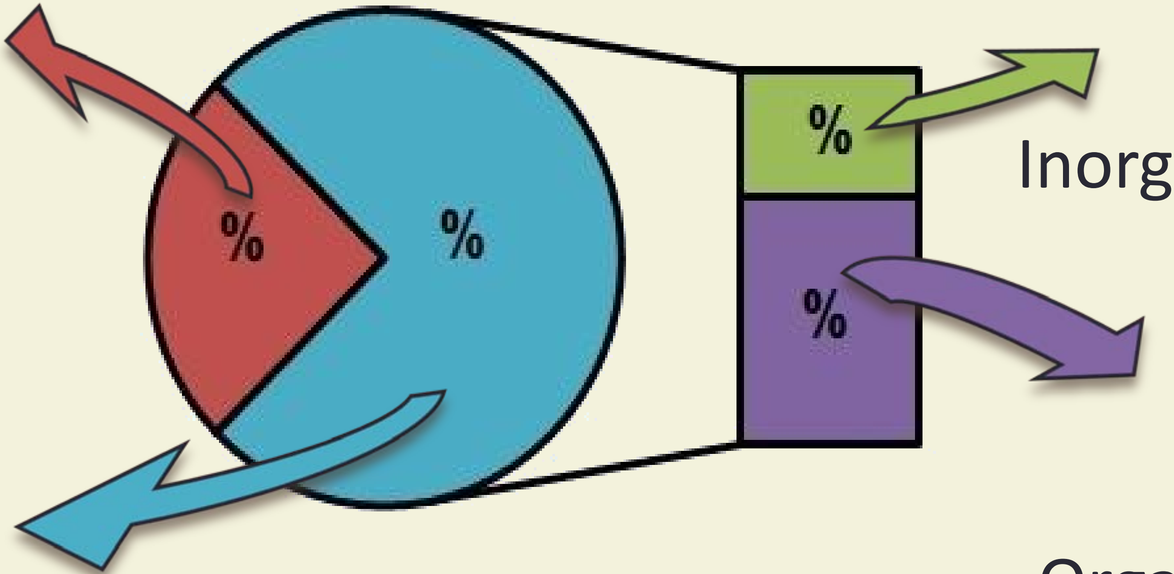


FRACTIONATION RESULTS



FRACTIONATION RESULTS

- Fractions shown as percentage of total P
- Inorganic and organic phosphorus together makes reactive P pool



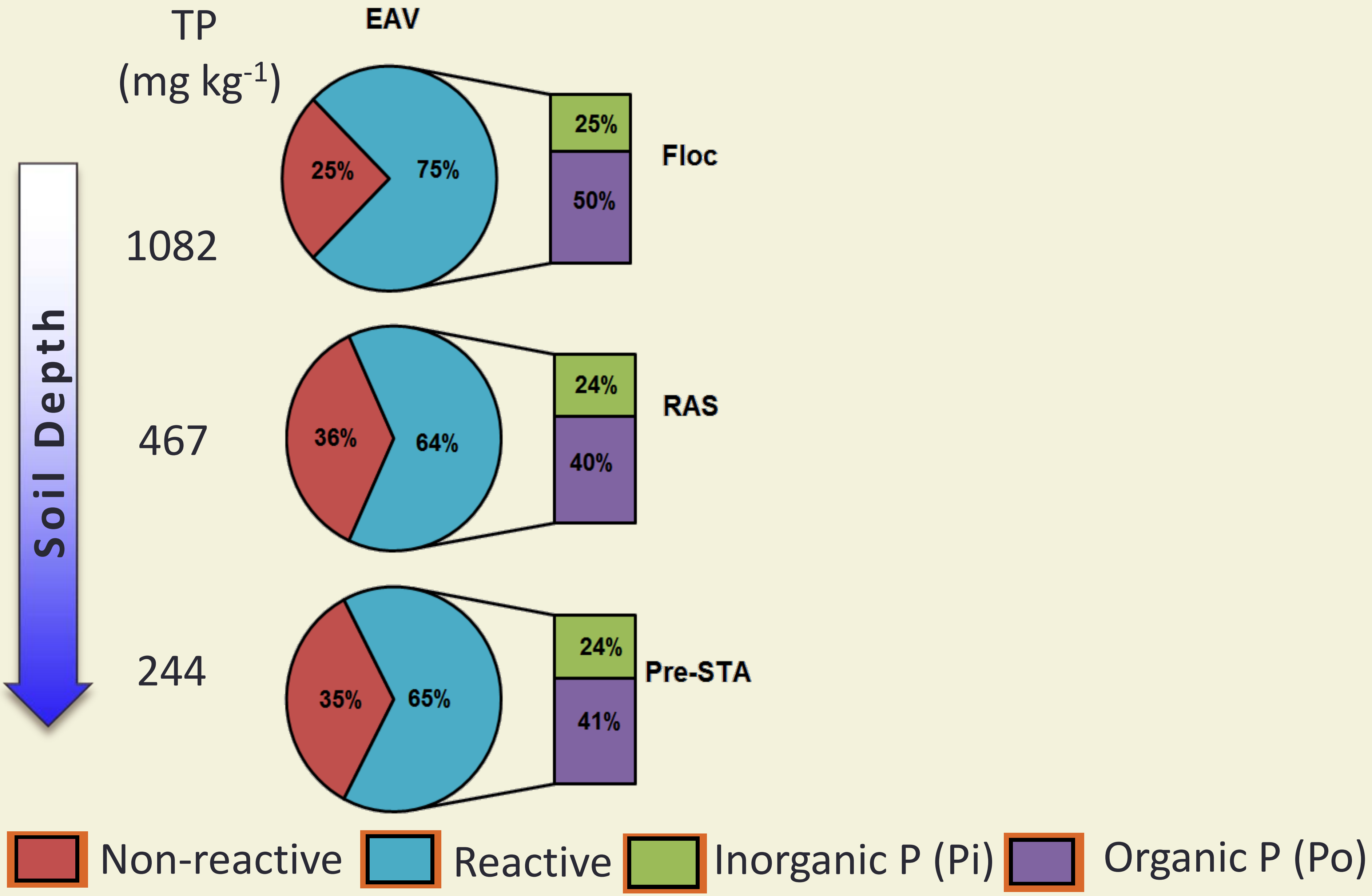
🟥 Non-reactive

🟦 Reactive

🟩 Inorganic P (Pi)

🟪 Organic P (Po)

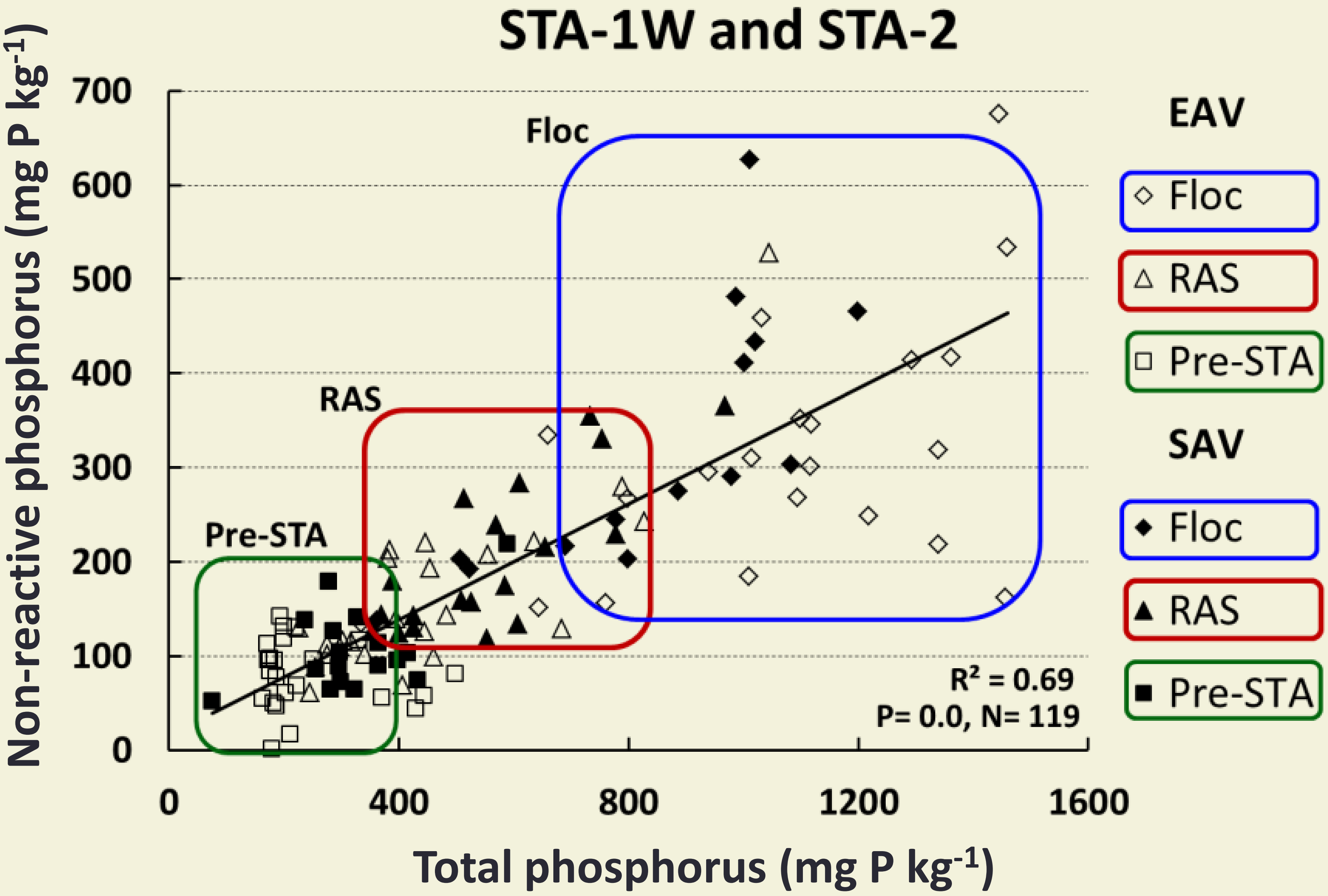
FRACTIONATION RESULTS



SOIL PHYSICO-CHEMICAL PARAMETERS

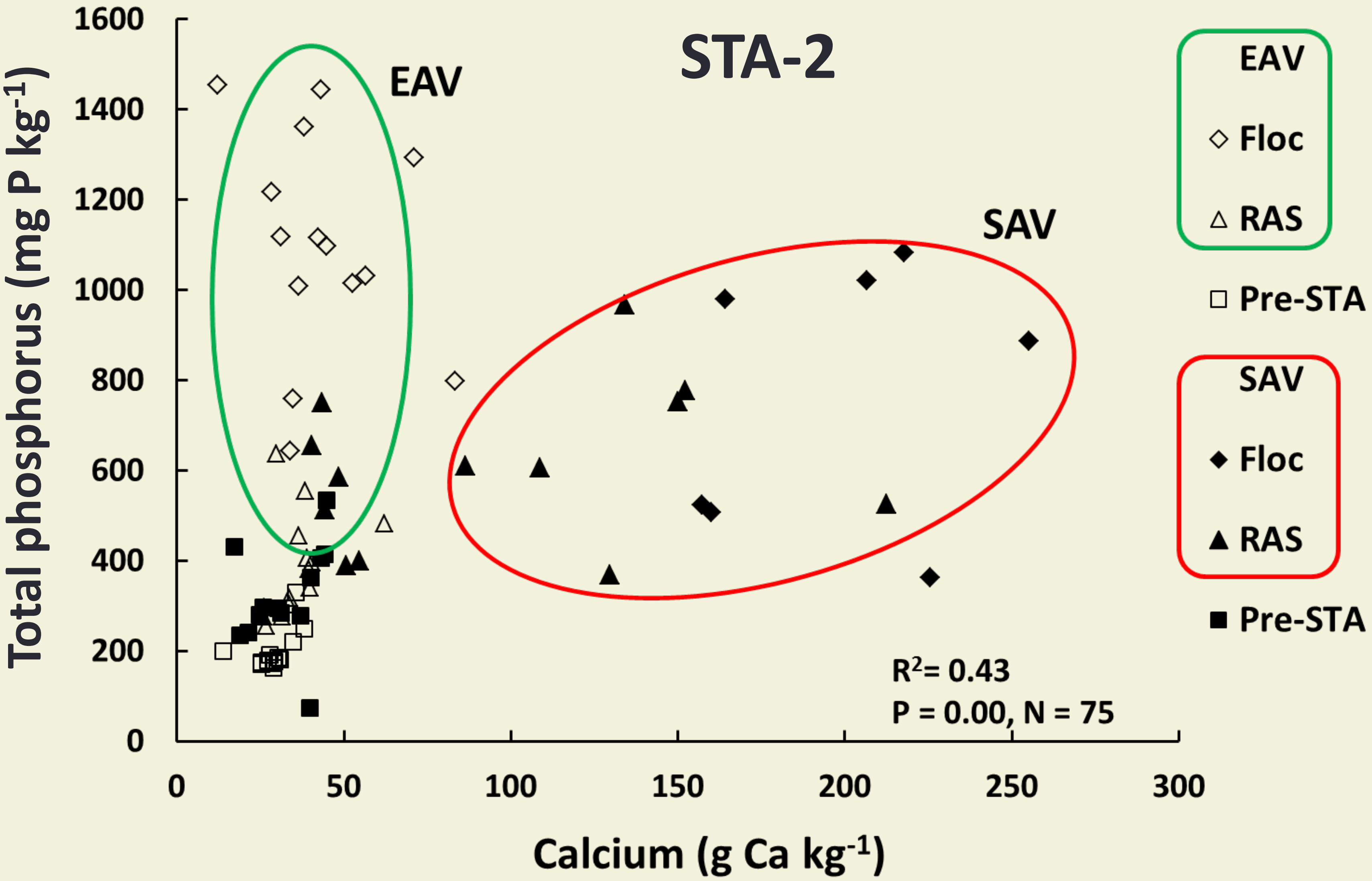
	Bulk density	LOI	TP	Ca	Mg
	g cm^{-3}	%	mg kg^{-1}	g kg^{-1}	g kg^{-1}
EAV					
Floc (n=23)	0.14	76	1082	40	2.8
RAS (n=26)	0.26	84	467	37	3.3
Pre-STA (n=24)	0.30	88	244	29	2.8
SAV					
Floc (n=14)	0.21	47	845	164	4.8
RAS (n=20)	0.32	74	579	78	4.6
Pre-STA (n=20)	0.35	79	335	34	2.7

NON-REACTIVE PHOSPHORUS POOL



PHOSPHORUS AND CALCIUM RELATIONSHIP

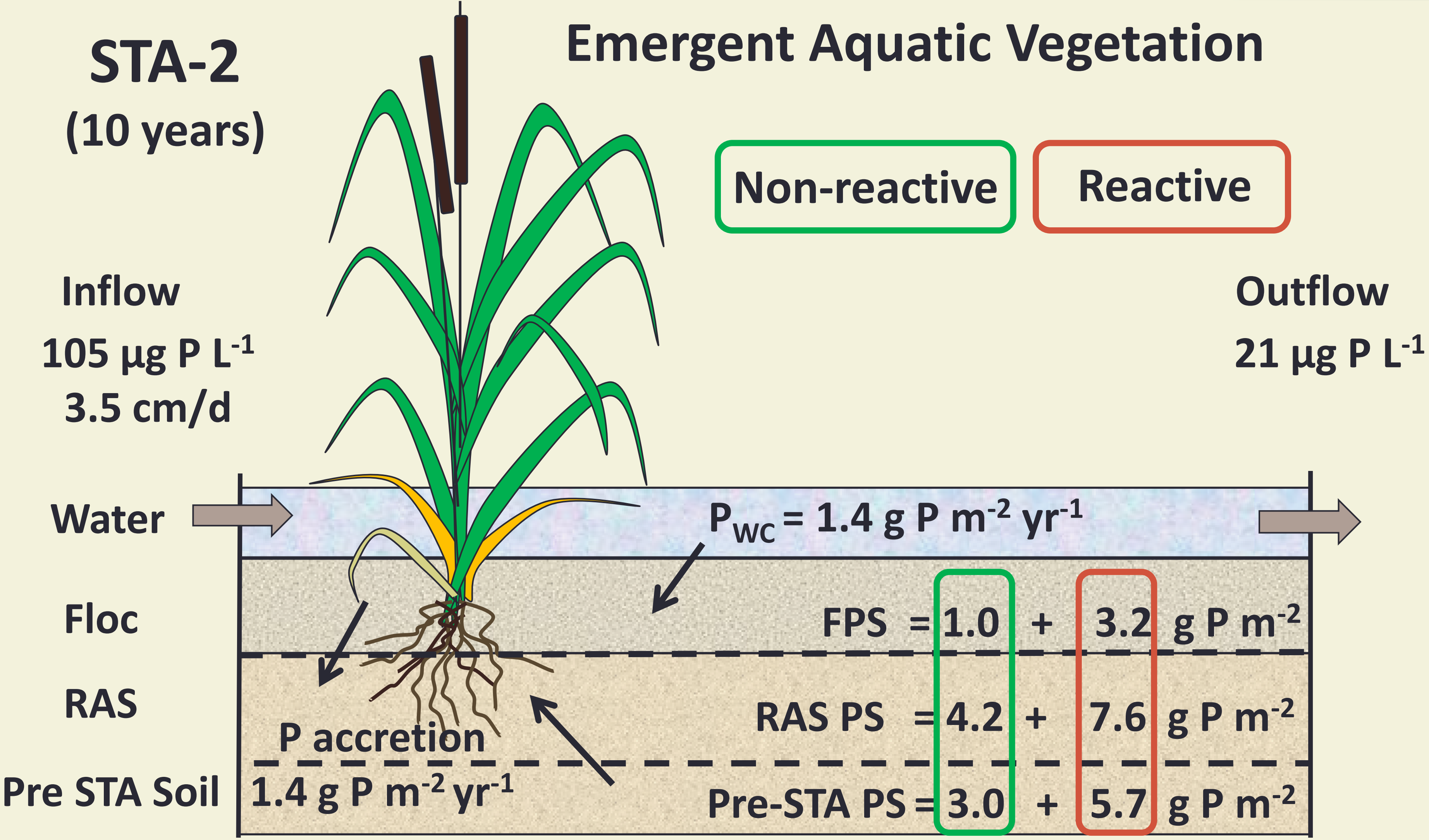
- Separation on the basis of – Vegetation and sample type



CONCLUSIONS AND IMPLICATIONS

- Approximately 20-30 % of TP present in non-reactive pools
- Reactive and non-reactive P pools did not differ significantly between SAV and EAV
- SAV could quickly remove P, but relative proportion of residual P is higher in EAV
- No difference between relative proportion of reactive and non-reactive P pools of floc, RAS, and pre-STA soil
- Organic P (Po) was higher in floc of EAV cells
- Accretion of Ca-rich layer in SAV cells suggest Ca-P co-precipitation contributing P uptake

SYNTHESIS



STA-2

(10 years)

Emergent Aquatic Vegetation

Non-reactive

Reactive

Inflow

105 µg P L^{-1}

3.5 cm/d

Outflow

21 µg P L^{-1}

Water

P_{WC} = 1.4 g P m^{-2} yr^{-1}

Floc

FPS = 1.0 + 3.2 g P m^{-2}

RAS

RAS PS = 4.2 + 7.6 g P m^{-2}

P accretion

Pre STA Soil

1.4 g P m^{-2} yr^{-1}

Pre-STA PS = 3.0 + 5.7 g P m^{-2}

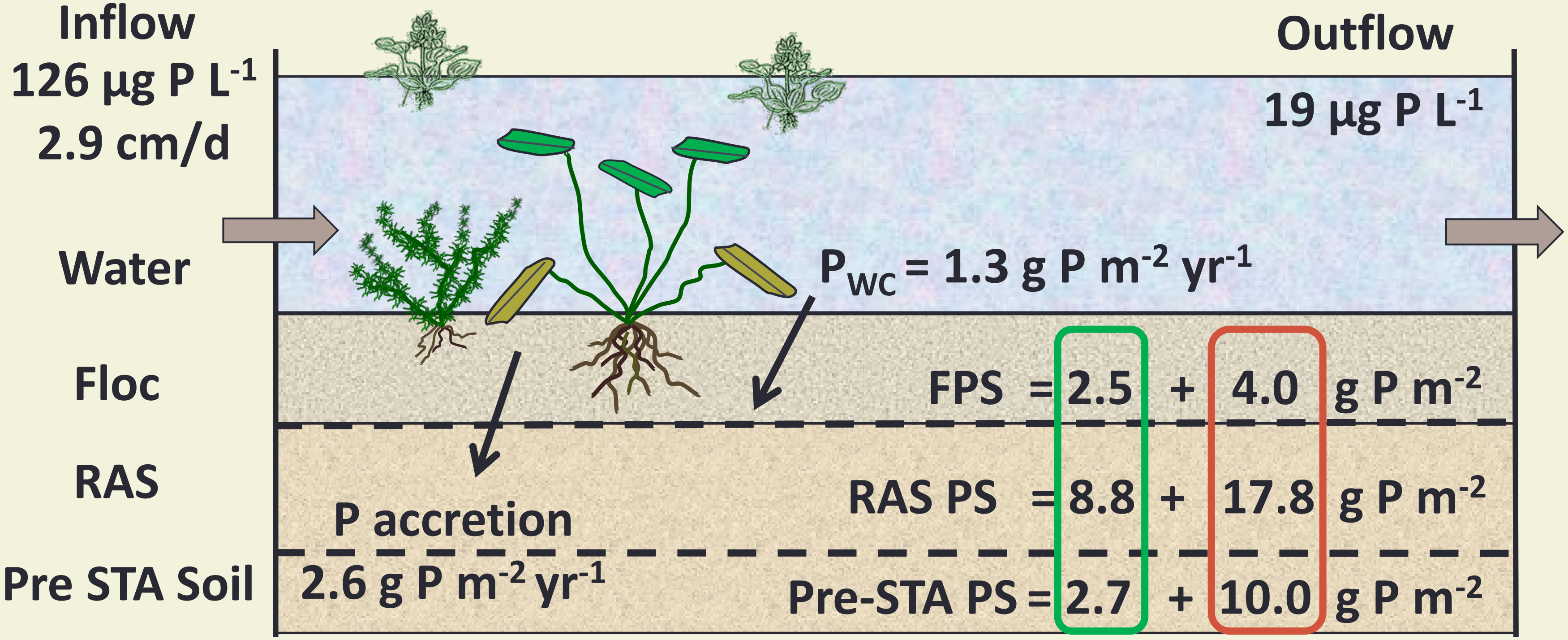
SYNTHESIS

Submerged Aquatic Vegetation

STA-2
(10 years)

Non-reactive

Reactive



Inflow
126 µg P L^{-1}
2.9 cm/d

Outflow
19 µg P L^{-1}

Water

P_{WC} = 1.3 g P m^{-2} yr^{-1}

Floc

FPS = 2.5 + 4.0 g P m^{-2}

RAS

RAS PS = 8.8 + 17.8 g P m^{-2}

P accretion
2.6 g P m^{-2} yr^{-1}

Pre STA Soil

Pre-STA PS = 2.7 + 10.0 g P m^{-2}

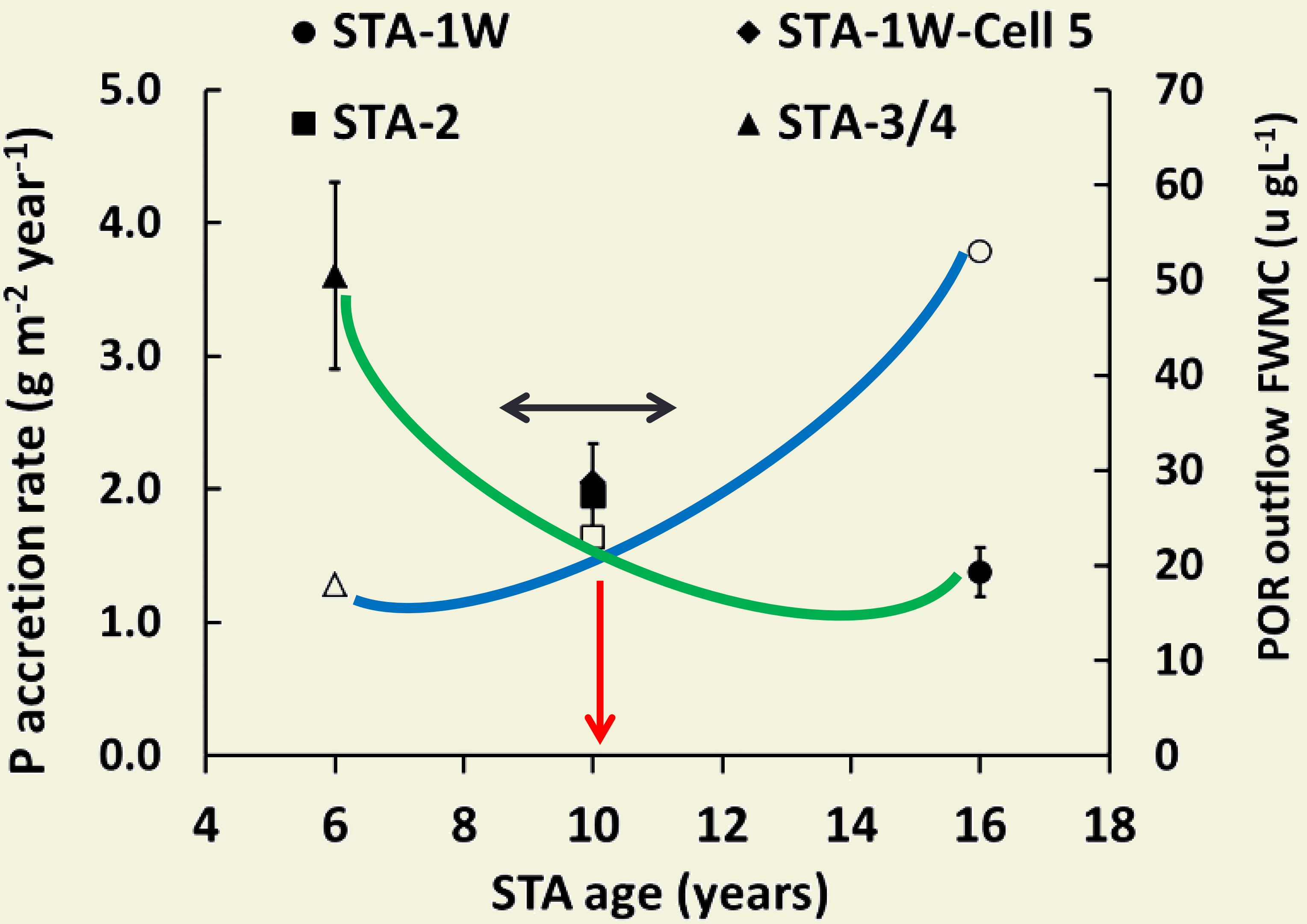
SYNTHESIS

- Functional P retention pathways in STAs involve biotic and abiotic processes
- Considerable movement and redistribution of P stocks within soil profile
- Majority of accreted P distributed in reactive pool while wetlands continue to retain P
- Phosphorus treatment efficiency varies but STAs also sequester other nutrients (C and N)
- STAs provide an effective, biological option for P removal

MANAGEMENT IMPLICATIONS

- Some evidence suggest soil accretion rate slows down with time – Scraping for rejuvenation?

MANAGEMENT IMPLICATIONS



MANAGEMENT IMPLICATIONS

- Some evidence suggest soil accretion rate slows down with time – Scraping for rejuvenation?
- SAV systems accrete Ca, could this affect performance of PSTA cells downstream?
- The data did not suggest clear difference in the chemical stability of accreted P, however differences due to physical characteristics may be important – SAV vs EAV particulate/ floc quality
- Assessment of STA’s life span on the basis of soil accretion rates and interventions for maintaining hydraulic flow and volume

POTENTIAL NEXT STEPS

- Intensive soil analysis – Spatial and temporal
- Quantification of soil accretion rates with respect to water quality effectiveness
- Stability of accreted P in other cells/STAs – Refined fractionation methodology and use of advance techniques (NMR, XANES)
- Ecosystem services valuation of STAs – potential benefits other than P removal

ACKNOWLEDGEMENTS

Financial support for this research

- SFWMD
- Everglades Foundation fellowship
- Society of Wetland Scientists research grant
- William K. Robertson scholarship
- UF office of research travel grant
- Davidson travel scholarship
- Florida Stormwater Association scholarship
- Graduate student council travel grants
- Soil and Water Science Department

ACKNOWLEDGEMENTS

- Advisor – Dr. K. Ramesh Reddy
- Committee members - Dr. Mark Brenner, Dr. Patrick Inglett and Dr. Alan Wright (UF). Dr. Michael Chimney (SFWMD)
- Personnel from SFWMD – Ms. Delia Ivanoff, Dr. Hongjun Chen, and Mr. Manuel Zamorano
- Wetland Biogeochemistry Lab – Ms. Yu Wang, Dr. Kathy Curtis and Mr. Gavin Wilson

THANK YOU!