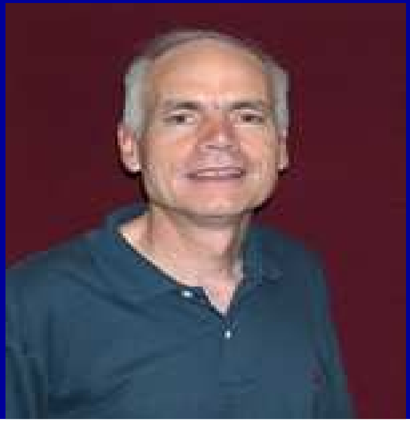
Amendments to Control Phosphorus Mobility

George O'Connor[1], Herschel Elliott[2], and Sampson Agyin-Birikorang[1]
[1]University of Florida and [2]Penn State University

O'Connor

Elliott



Agyin-Birikorang

The Phosphorus Problem

- High-P soils + off-site P loss = water quality degradation
- Greatest risk
  - Small soil retention capacity – PSI<0.25
  - Short connectivity distances
  - Sensitive water bodies
  - Coastal plain soils
  - Most of Florida!

Best Management Practices

- Reduce P inputs:
  - NMPs, CNMPs
  - Long “lag” times
- Reduce P solubility
- Increase soil retention
- Intercept P released

} Amenable to Amendment Augmentation

Objectives

- Describe BMP augmentation with amendments
  - Basis
  - Effectiveness
  - Potential concerns
  - Focus
    - Drinking water treatment residuals (WTRs)
    - Strategies for use

Wanielista et al. 2009; Agyin-Birikorang et al. 2009 (2); O'Connor et al. 2005

Reduce P Solubility

- Adjust soil or water pH – maintenance
- Remove P from water – alum
  - Lakes – e.g., Lake Langsjon, Sweden
    - $Al^{3+} + 6\ H_2O \rightarrow 3H_2O + Al(OH)_{3(s)} + P \rightarrow$

    flocculant enmeshment and adsorption of P

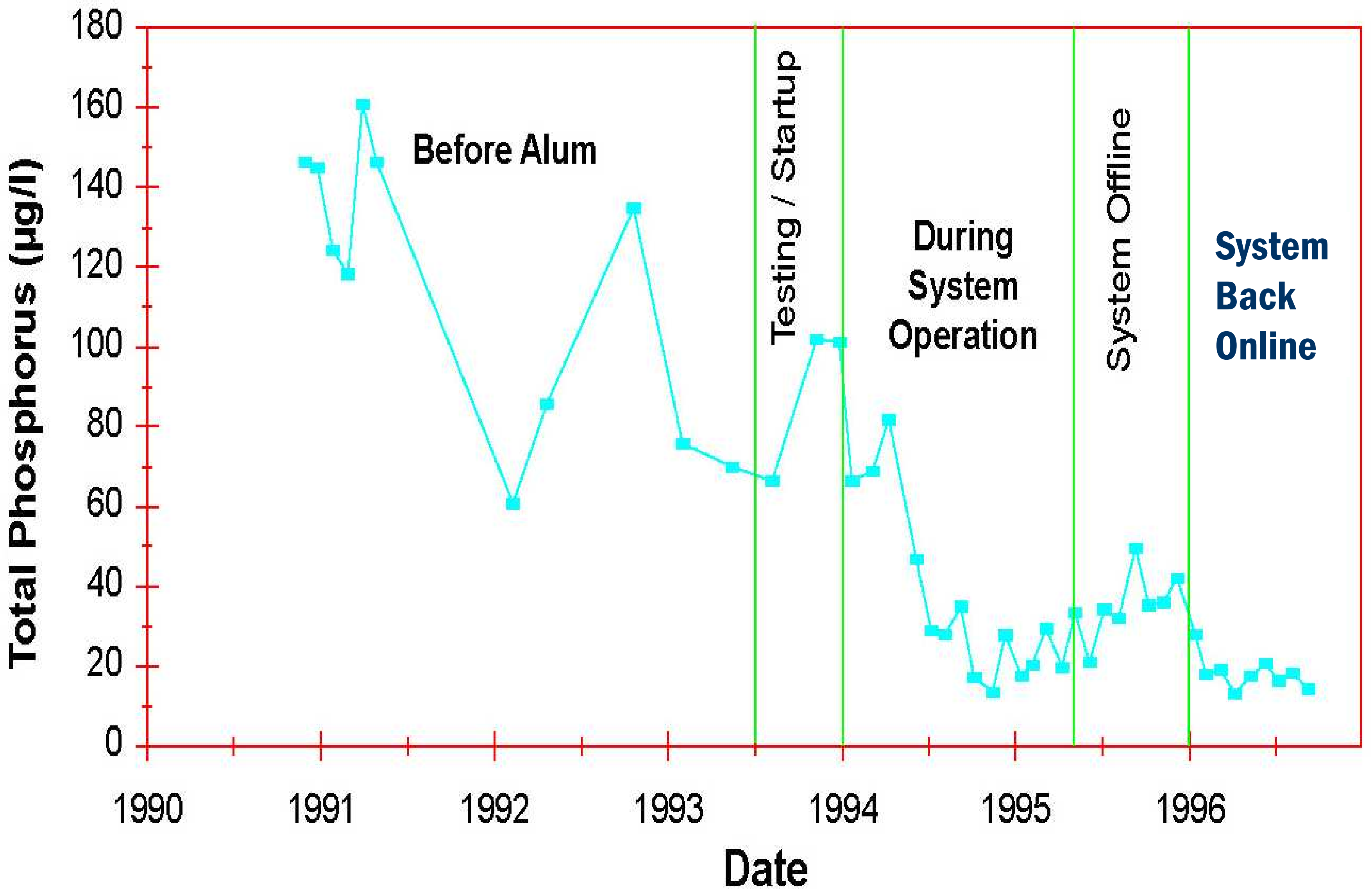
    and/or

    - $Al^{3+} + H_nPO_4^{n-3} \rightarrow AlPO_{4\ (s)} + nH^+$

    precipitation

    - Sometimes with polymers to enhance flocculation

Lake Lucerne, FL



Harper et al., 1998

Storm Water

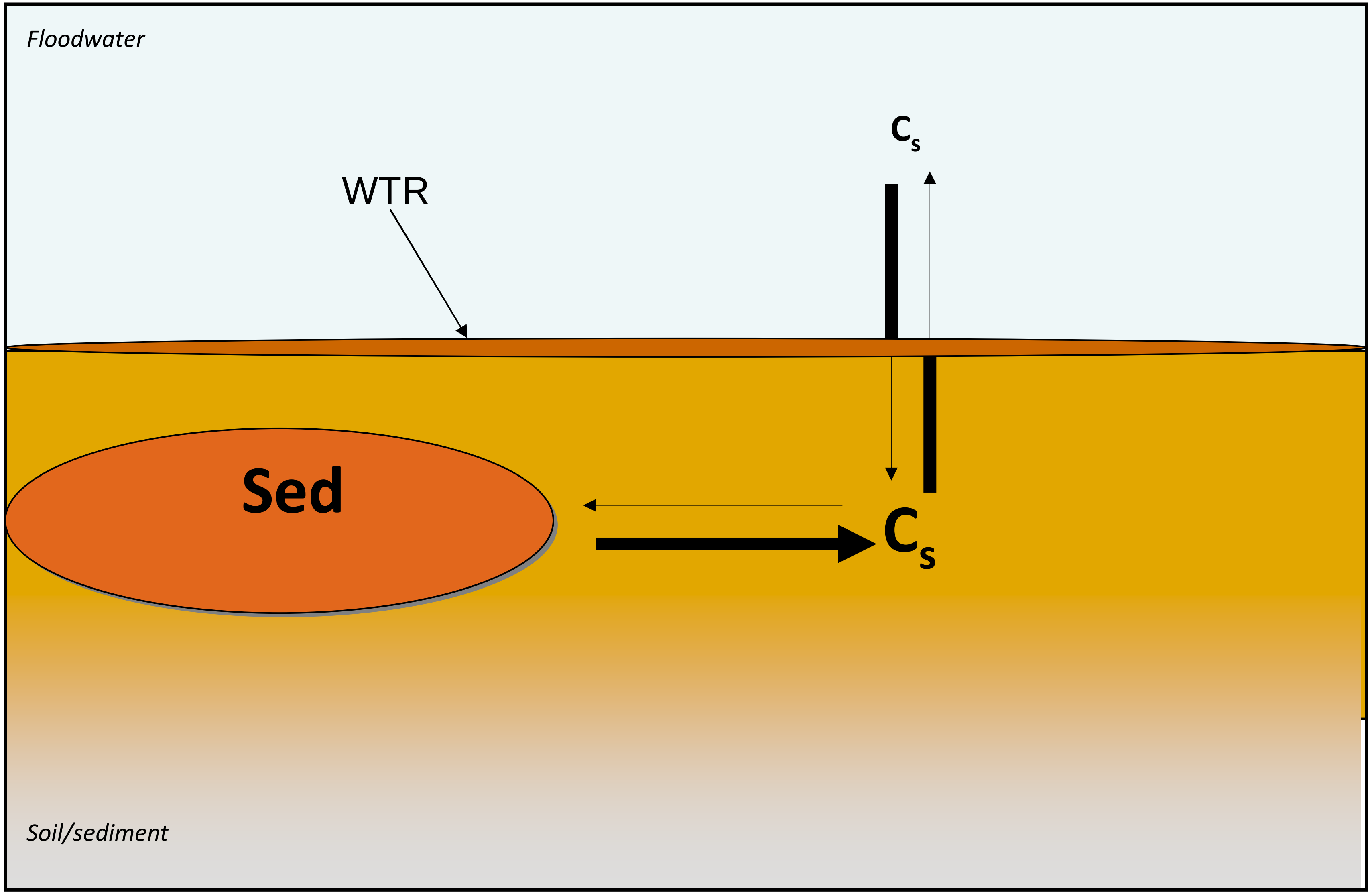
PARAMETER	SETTLED WITOUT ALUM	ALUM DOSE (mg L^{-1} as Al)		
		5 mg L^{-1}	7.5 mg L^{-1}	10 mg L^{-1}
	%			
Diss. Organic N	20	**51**	62	65
Particulate N	67	**88**	94	96
Total N	20	**25-50**	30-60	40-70
Diss. Ortho-P	17	**96**	98	98
Particulate P	71	**82**	94	95
Total P	45	**86**	94	96

Harper et al., 1998

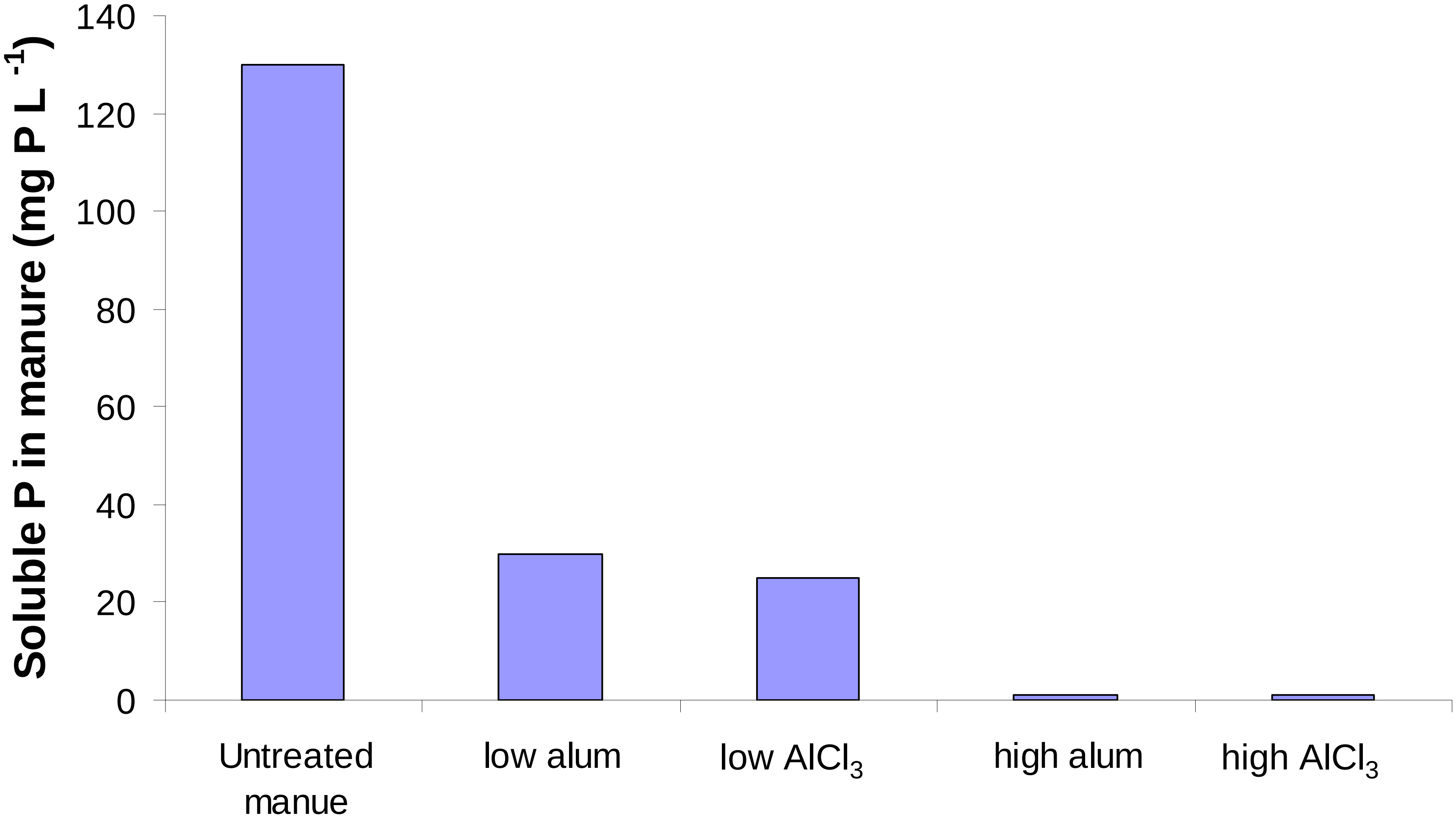
Reduce Sediment P Solubility

- Limit diffusion release of P from sediments in storm water treatment areas (STAs) and constructed wetlands
  - Al^{3+} (alum) and $Al(OH)_{3(s)}$ reacts with sediment surface-bound P to form barrier to diffusion of P from sediments to water column
  - Al serves as large capacity sink for P from above and below

After Amendment (WTR) application

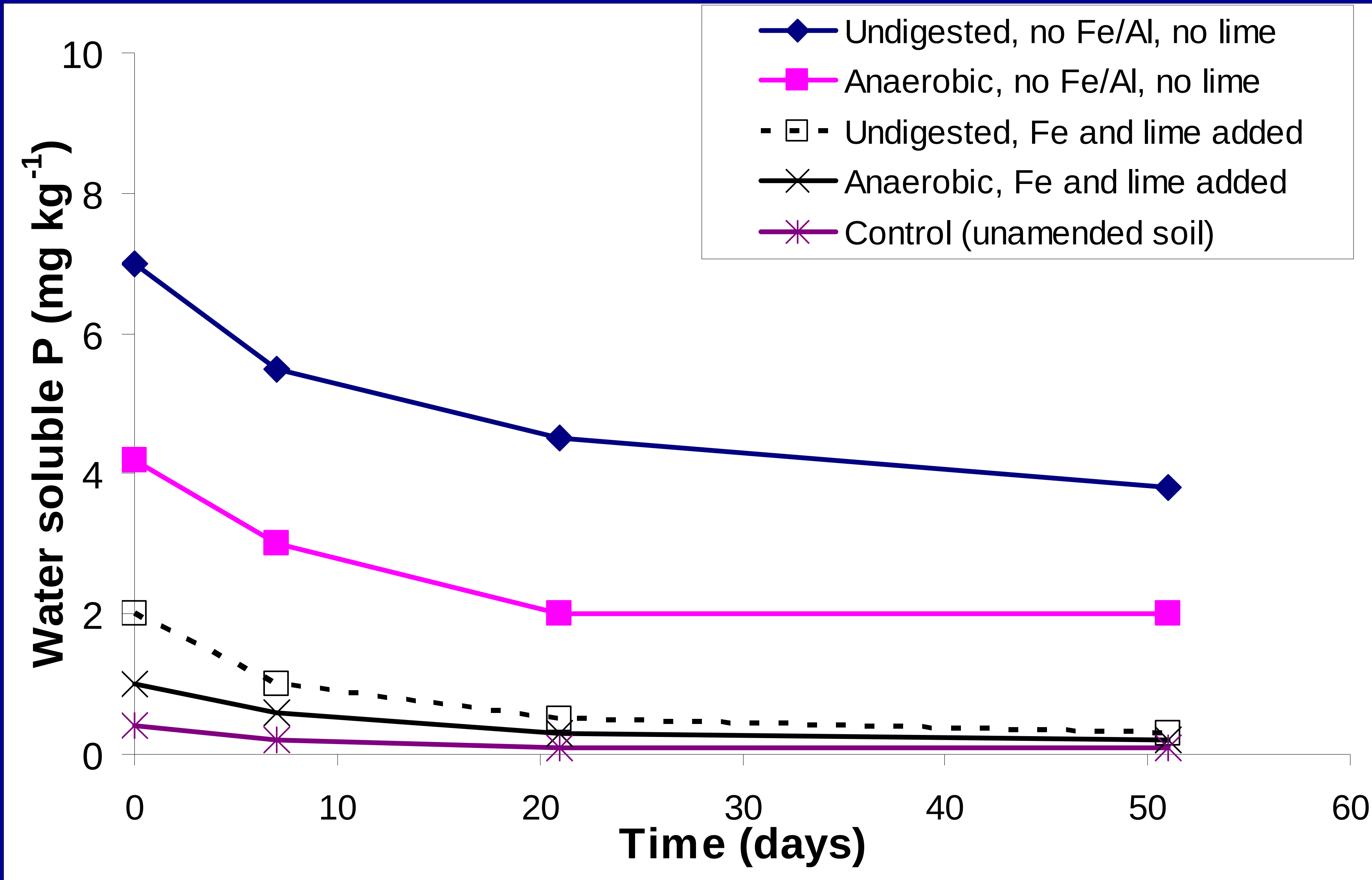


Reduce P-Source Solubility



Smith et al., 2001

Reduce P-Source Solubility



Maguire et al., 2001

Amendment Characteristics

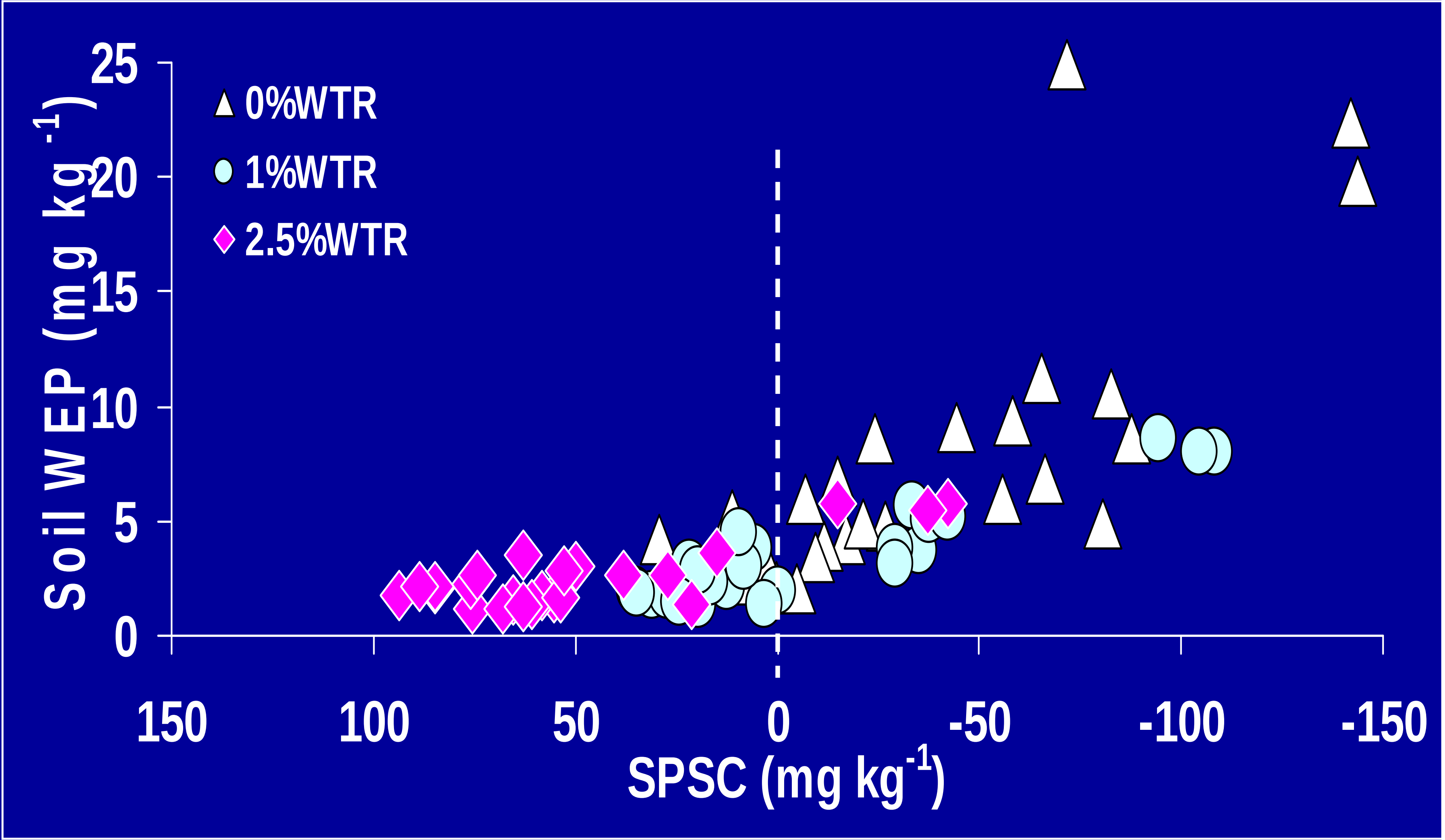
Amendment	pH	Mn	Cu	Zn	As	Se	Mo
		----------------------mg kg^{-1} ----------------------					
M-Al-WTR	5.0	40	60	20	9.5	1.7	20
O-Al-WTR	6.8	50	10	10	13	2.3	2.2
Fe-WTR	6.1	600	480	30	44	2.3	71
Ca-WTR	8.9	10	10	10	0.3	0.1	0.3
Coal slag	3.7	140	80	440	51	22	173
Pro-Sil	11	820	40	40	1.4	3.8	42
Fe-humate	3.4	20	20	10	1.8	13	0.3
Gypsum	8.3	10	10	10	0.1	2.8	1.7
Lime	8.9	30	10	10	1.9	0.8	0.6
DinoSoil	3.6	350	30	90	16	1.0	0.2

Increase Soil Retention of P

P source	Treatment	Mean total P leached	Applied P leached
		mg	%
TSP	-	75.7	20.7
TSP	Al-WTR	2.60	0.73
TSP	Fe-WTR	12.8	3.5
TSP	Ca-WTR	9.1	2.5
TSP	Hematite	73.1	20.0
None	Fe-WTR	0.16	0.049
None	-	0.29	NA

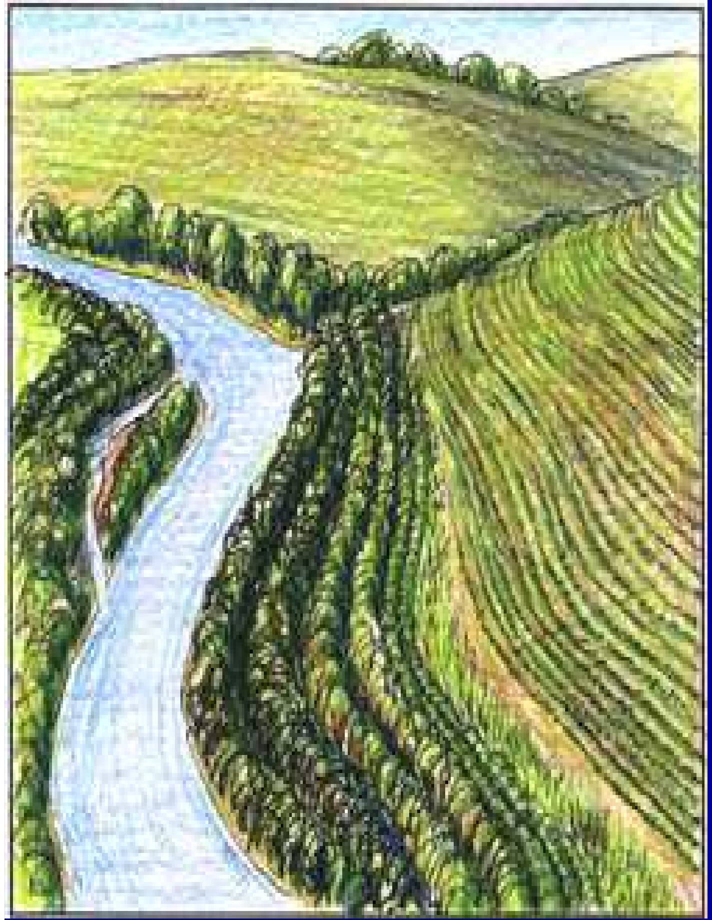
Elliott et al., 2002

Increase Soil Retention of P



Oladeji, 2006

Buffer Strip Enhancement



WTR	A	B	C	D	E
WTR rate (Mg ha^{-1})	---% Soluble P Reduction------				
5	3	7	33	38	33
10	25	40	46	49	51
20	71	67	79	84	86

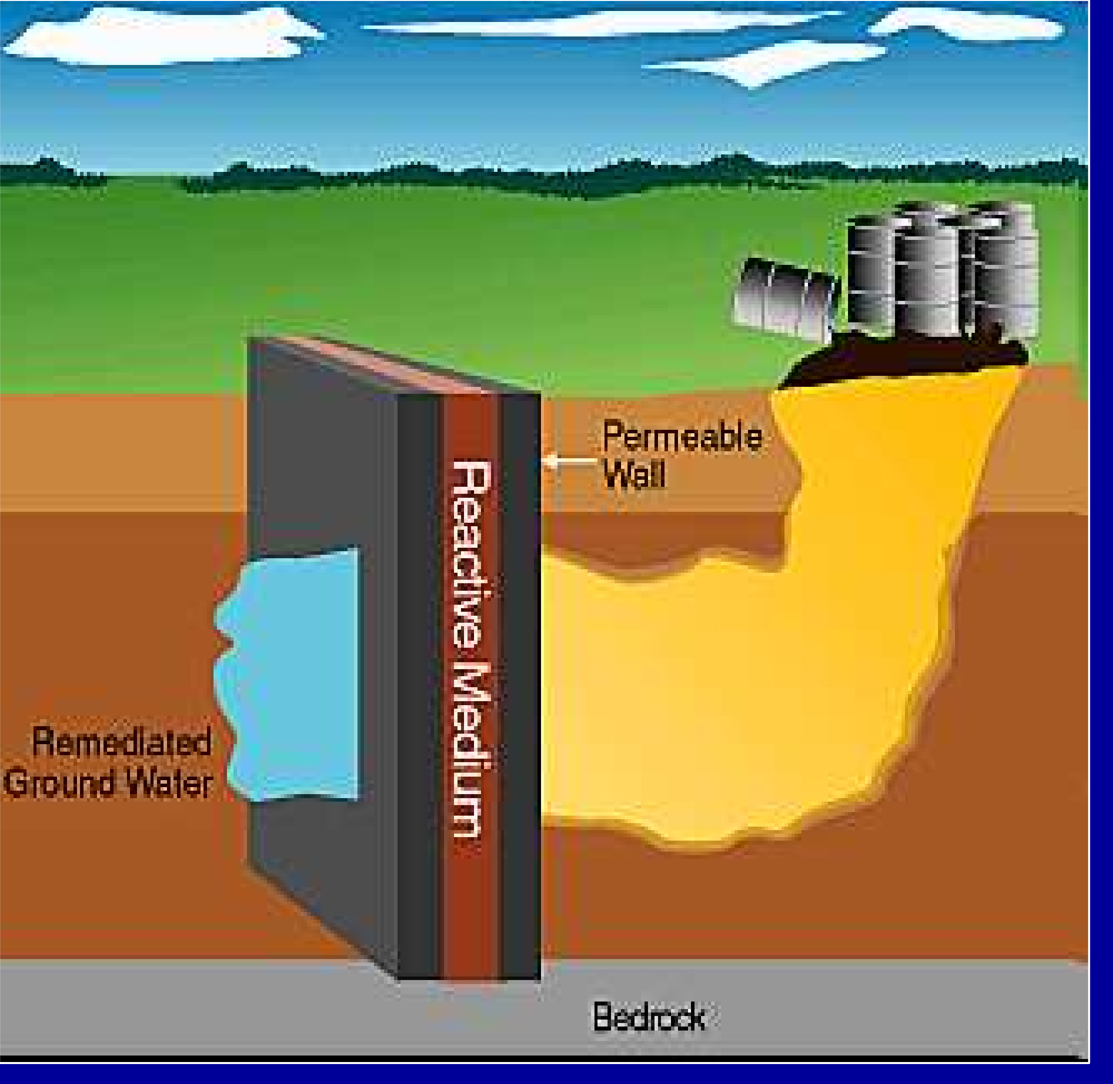
Dayton and Basta, 2005

Control of Soil Legacy P

WTR treatments		Cumulative P Leached	
Rate (g kg^{-1})	Extent of WTR incorporation (%)	Mass (mg)	% initial P load
0	-	408	32
25	50	230	13
50	50	210	12
100	50	194	10
25	100	59	4
50	100	18	1
100	100	4.4	0.3

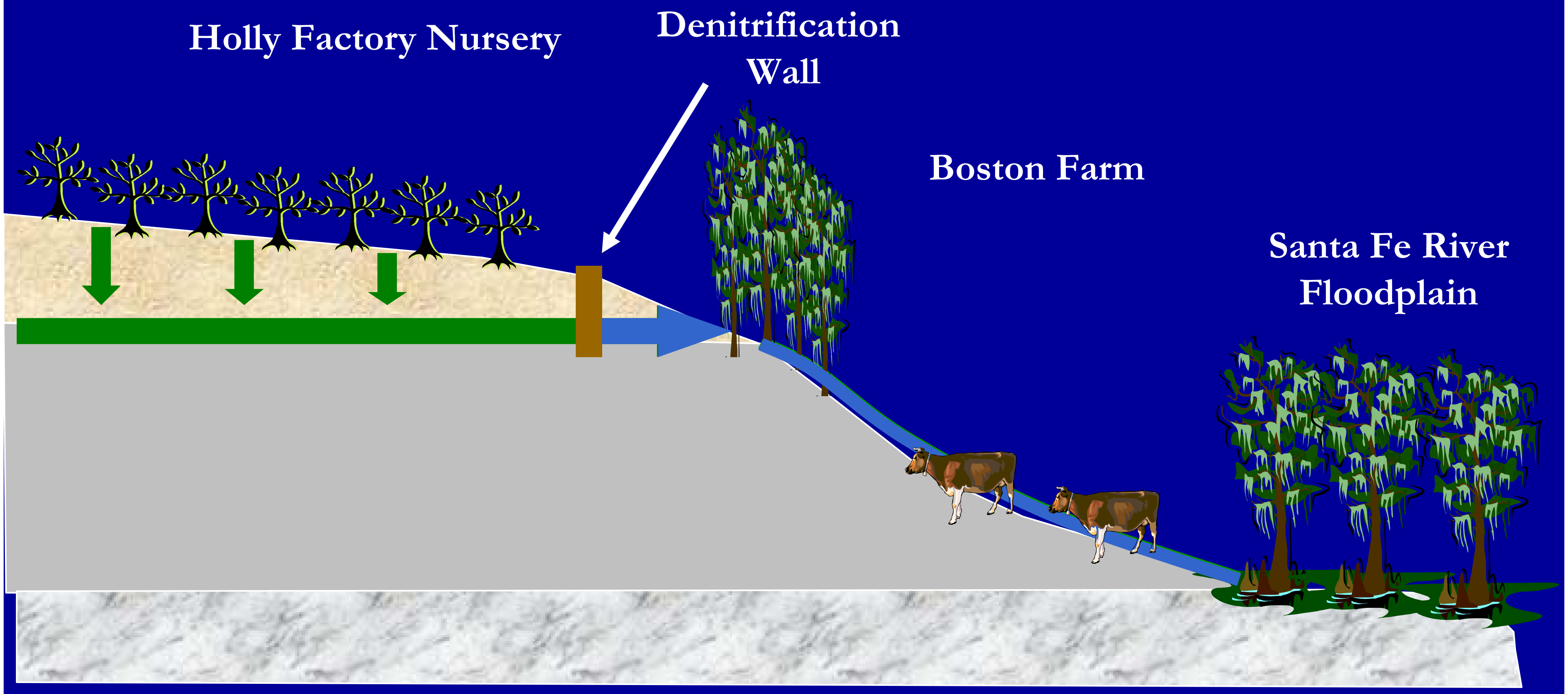
Silveira et al., 2006

Intercept Released P: Permeable Reactive Barriers

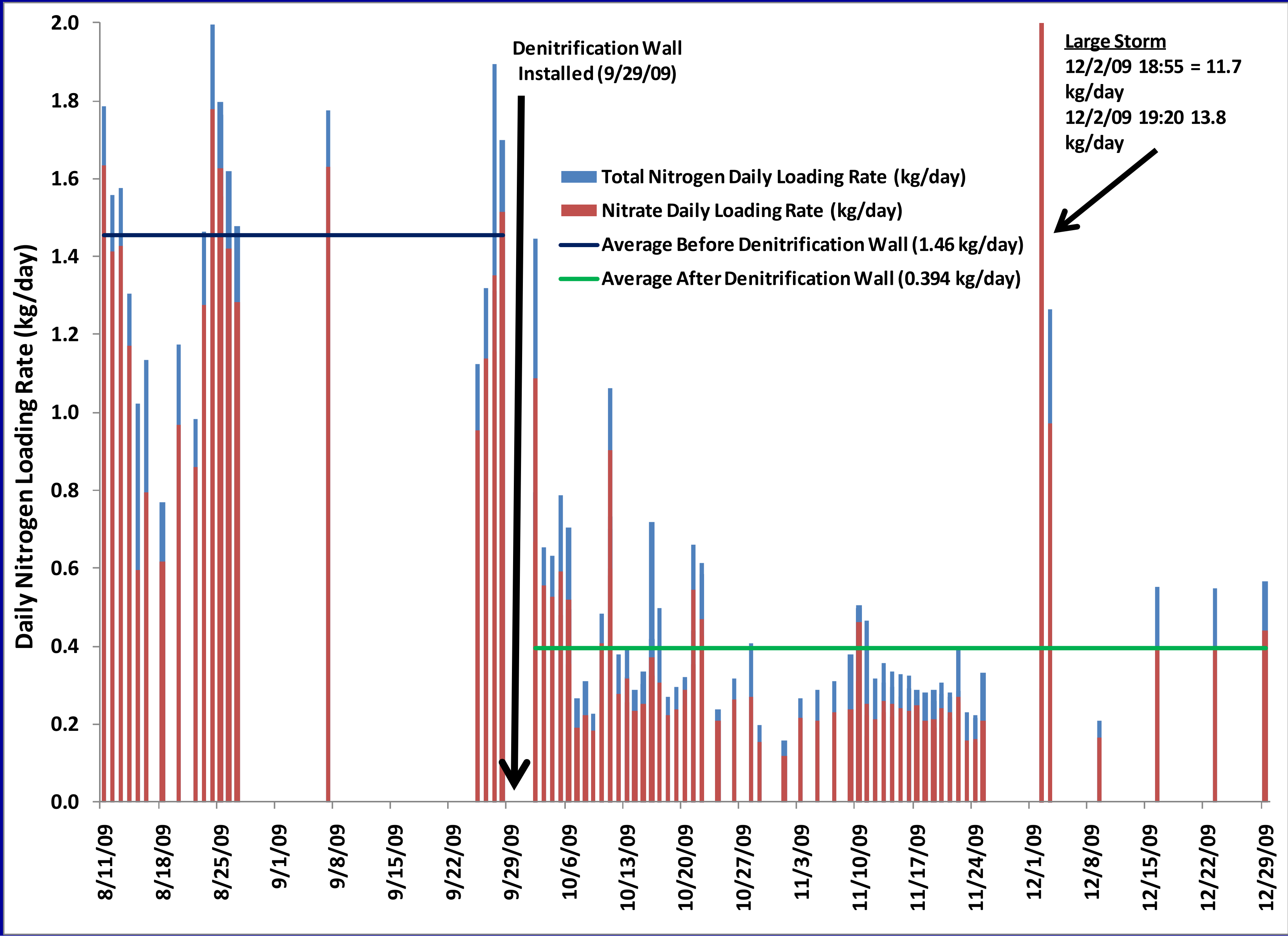


http://www.p2pays.org/ref/14/0_initiatives/init/winter99/images/Barrier.gif

Permeable Reactive Barrier: Denitrification Wall Demonstration



SW3 Nitrogen Loading



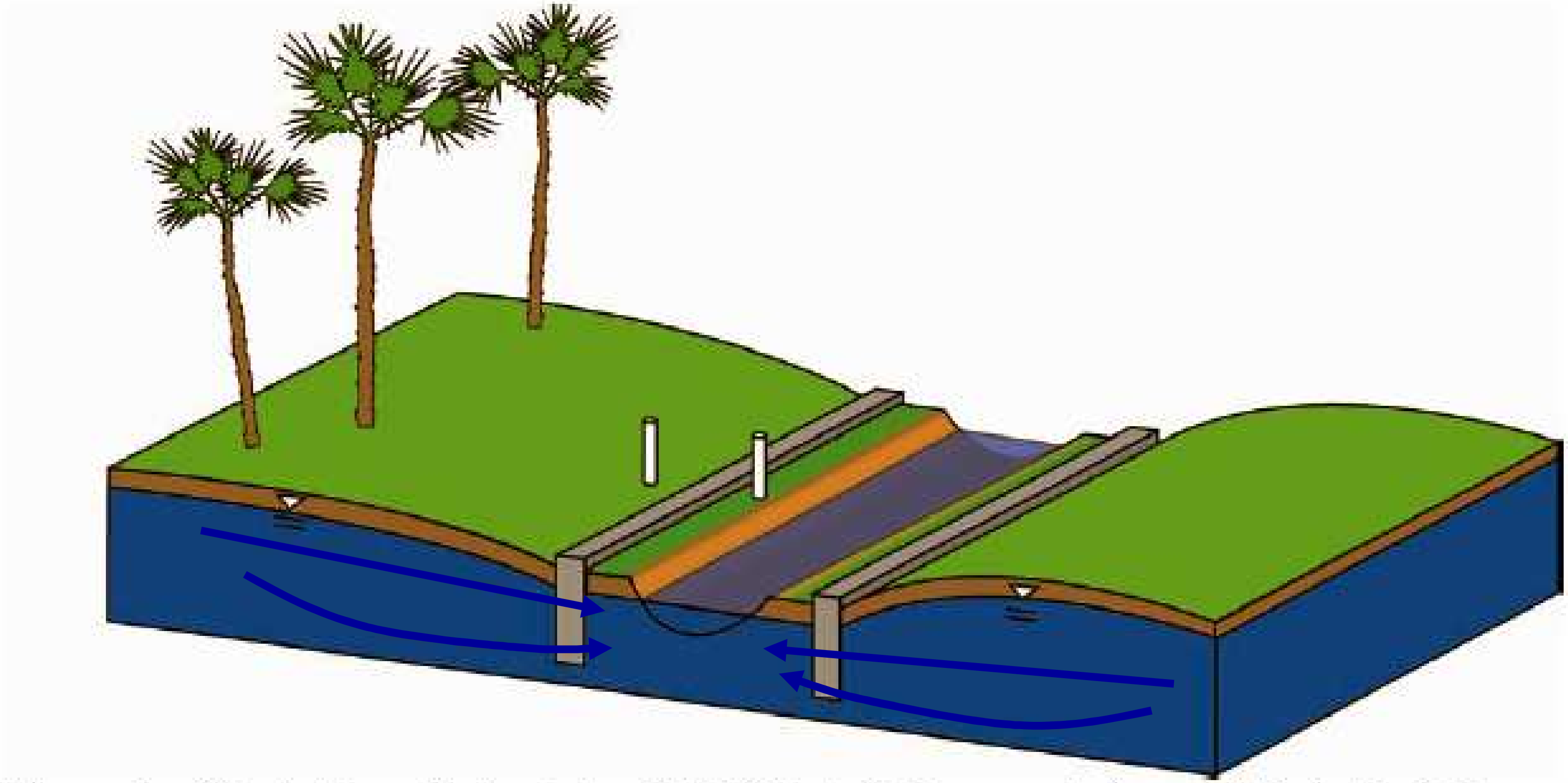
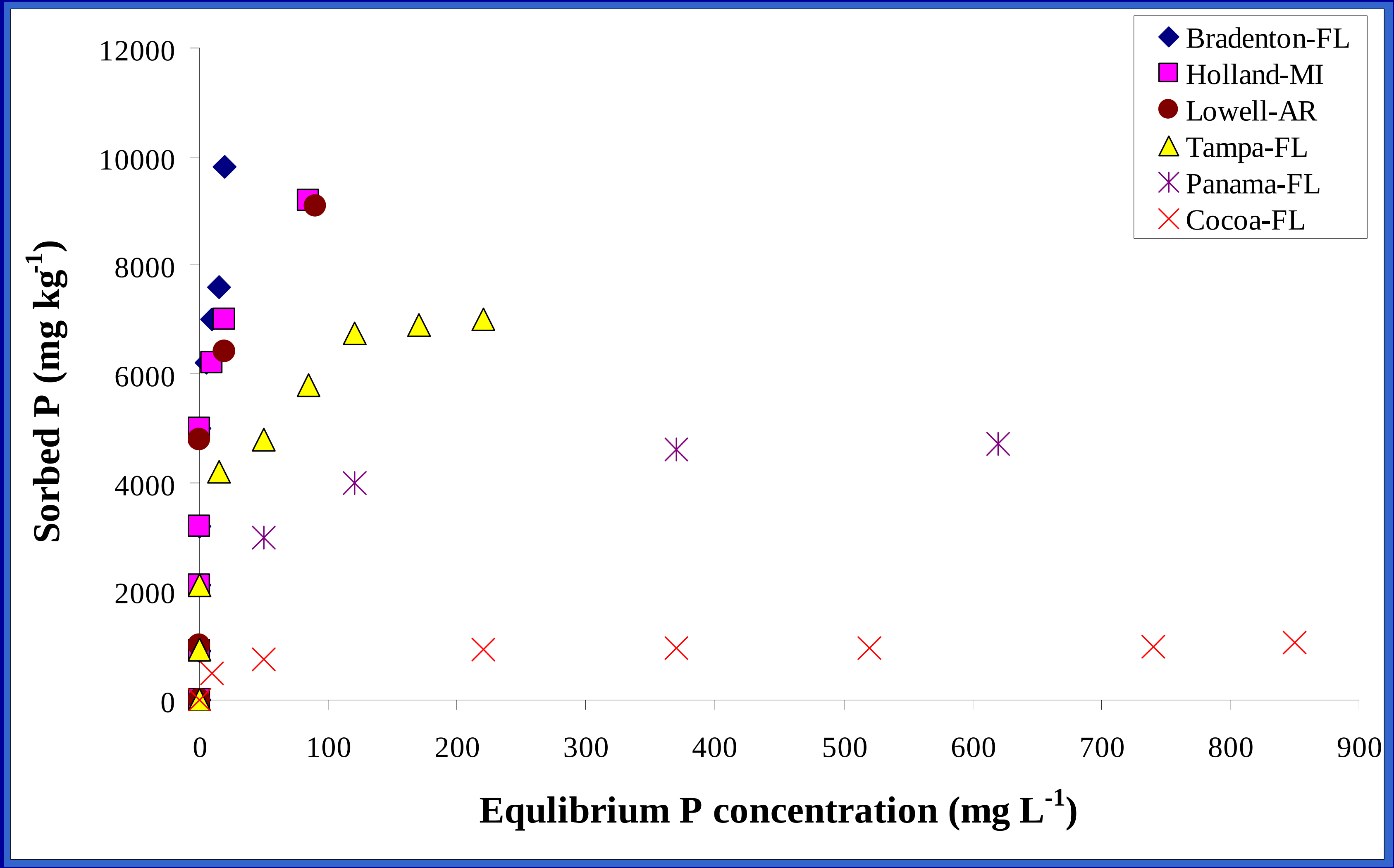


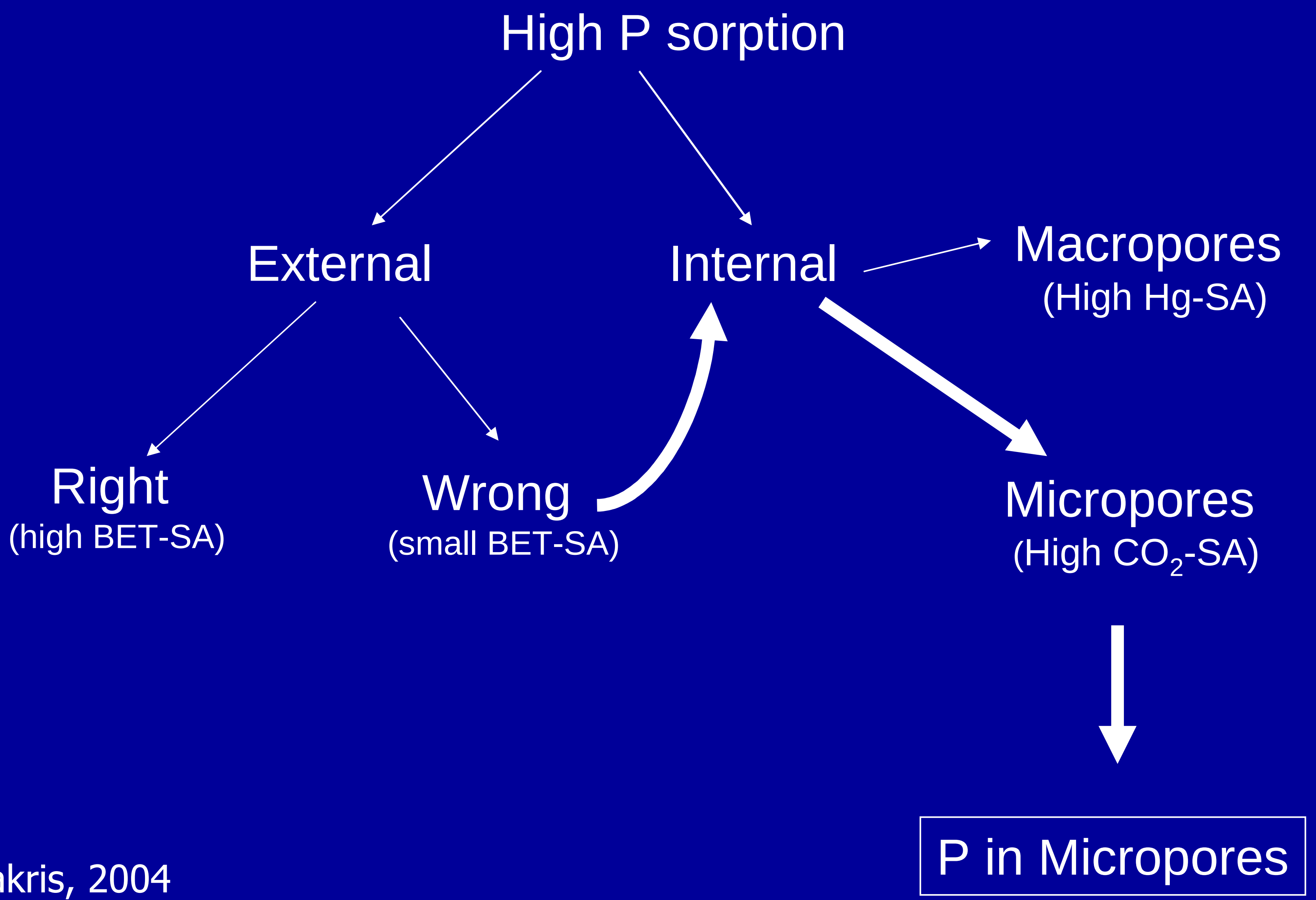
Figure 1a. Illustration of a buried-wall PRB installed near a drainage ditch in the Lake Okeechobee Basin. The PRB will intercept phosphorus in the groundwater before entering the ditch. Wells are shown up- and down-gradient of one of the PRBs to monitor phosphorus removal performance.

WTRs: All are not the Same!



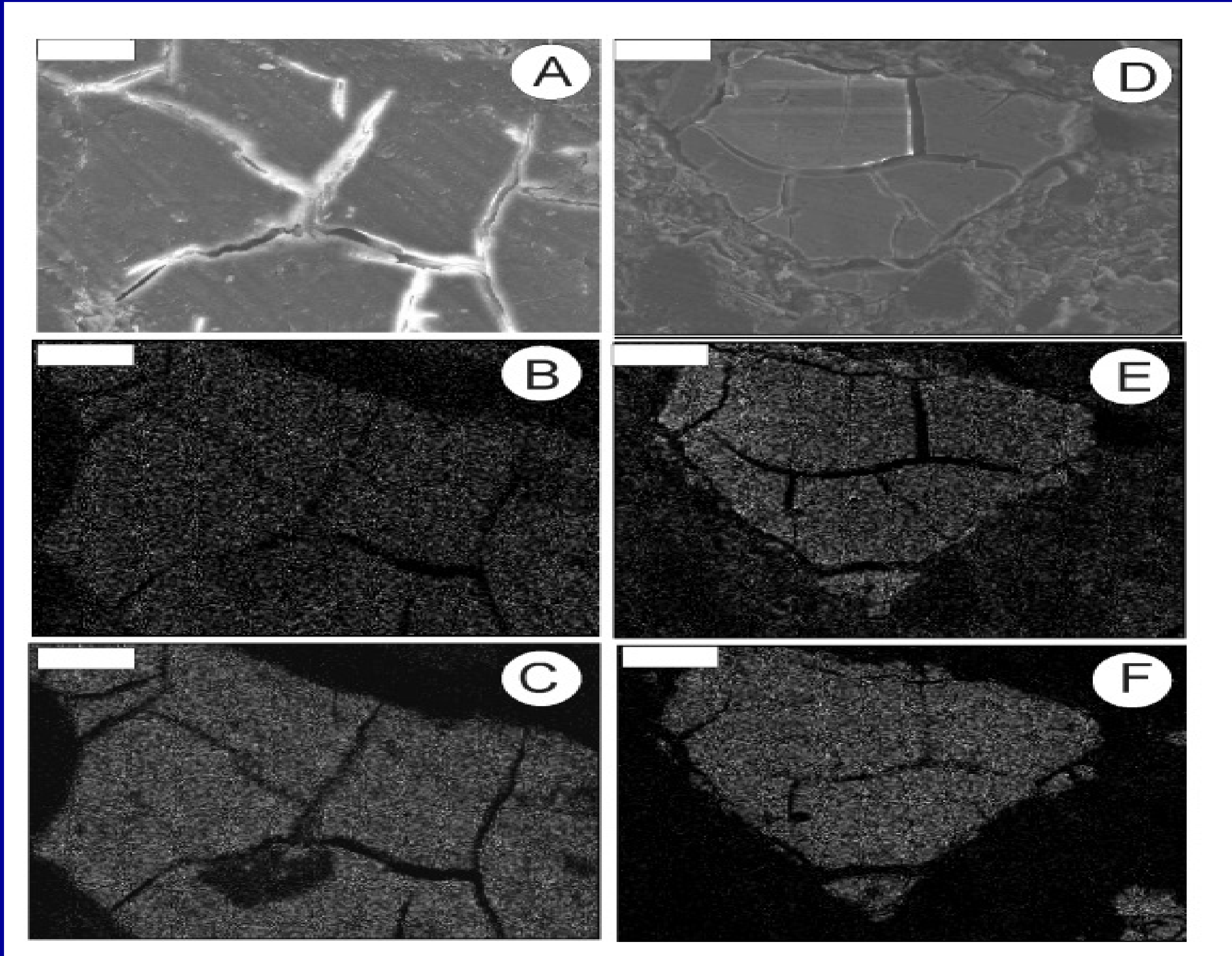
Makris and O'Connor, 2007

WTR Mechanisms:



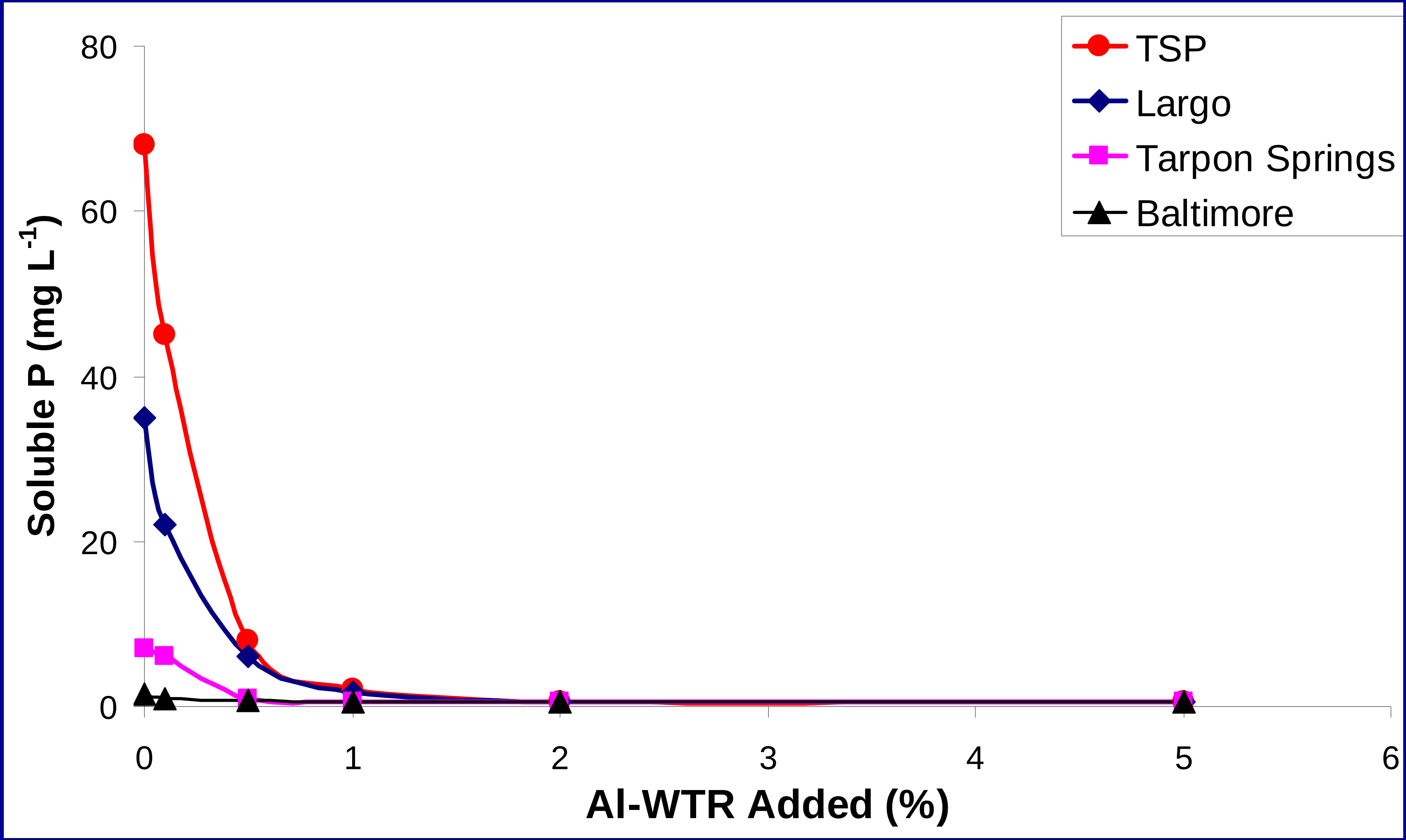
Makris, 2004

WTR Mechanisms



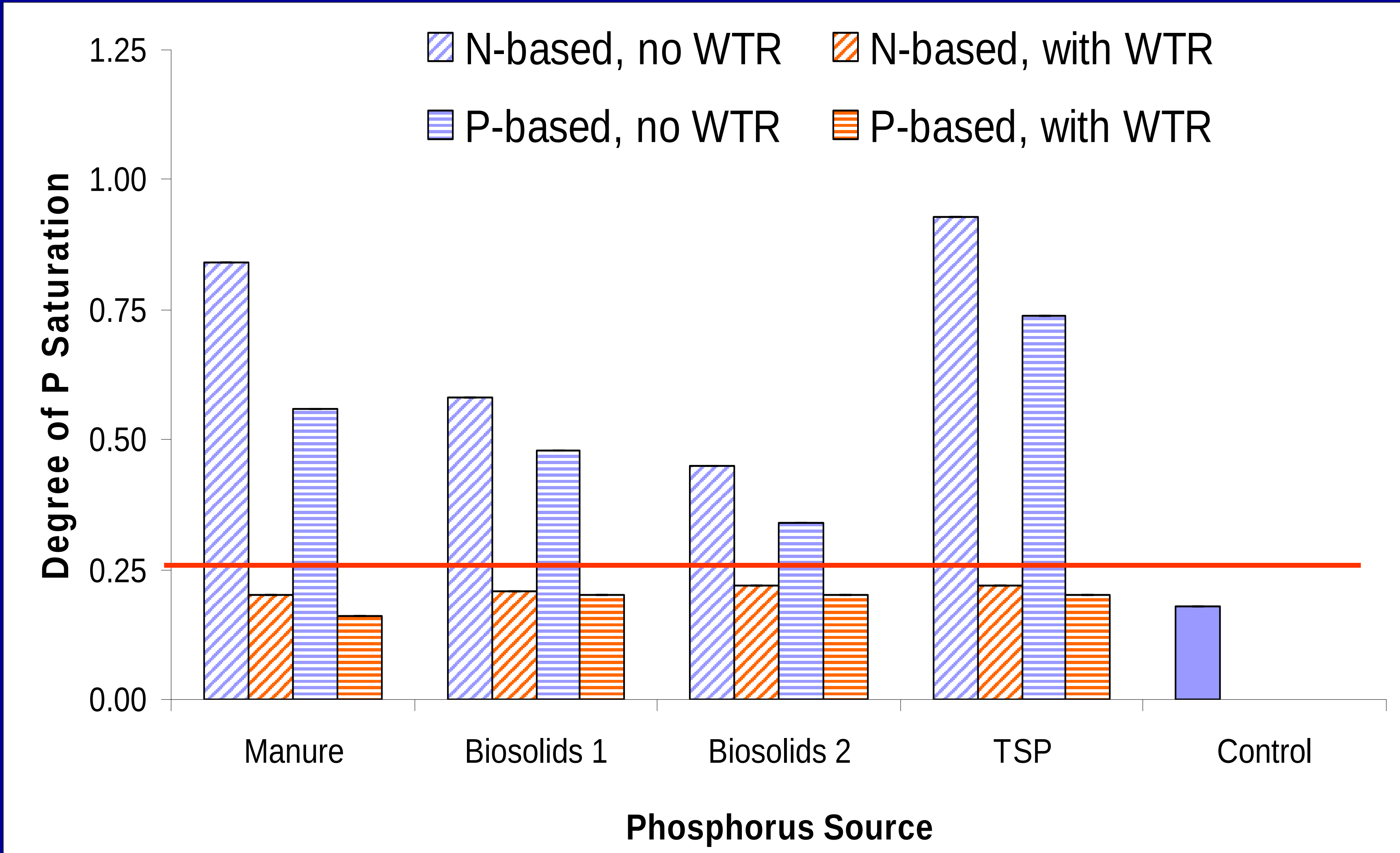
Makris and O'Connor, 2007

WTR research and case studies



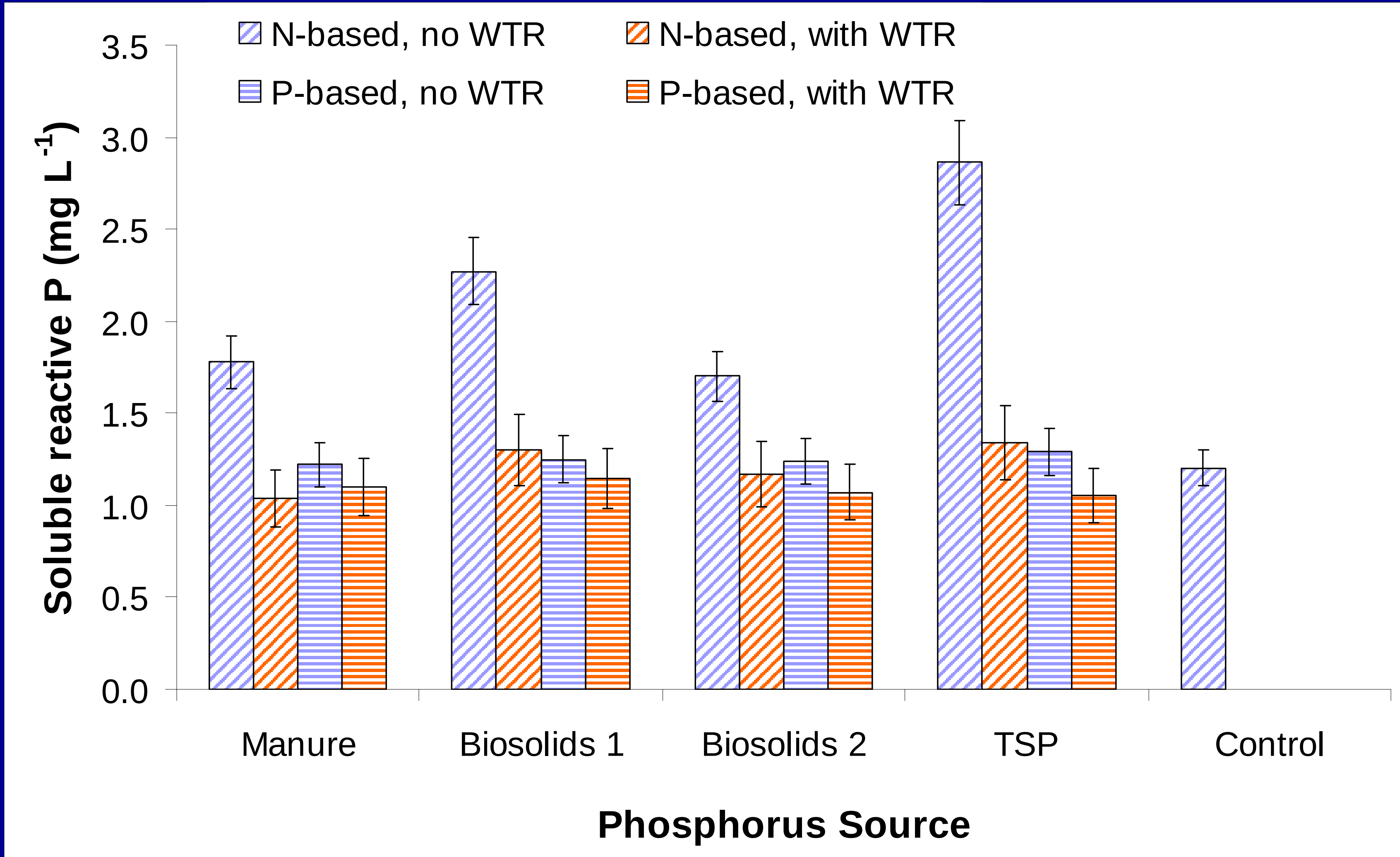
Elliott et al., 2002

WTR research and case studies



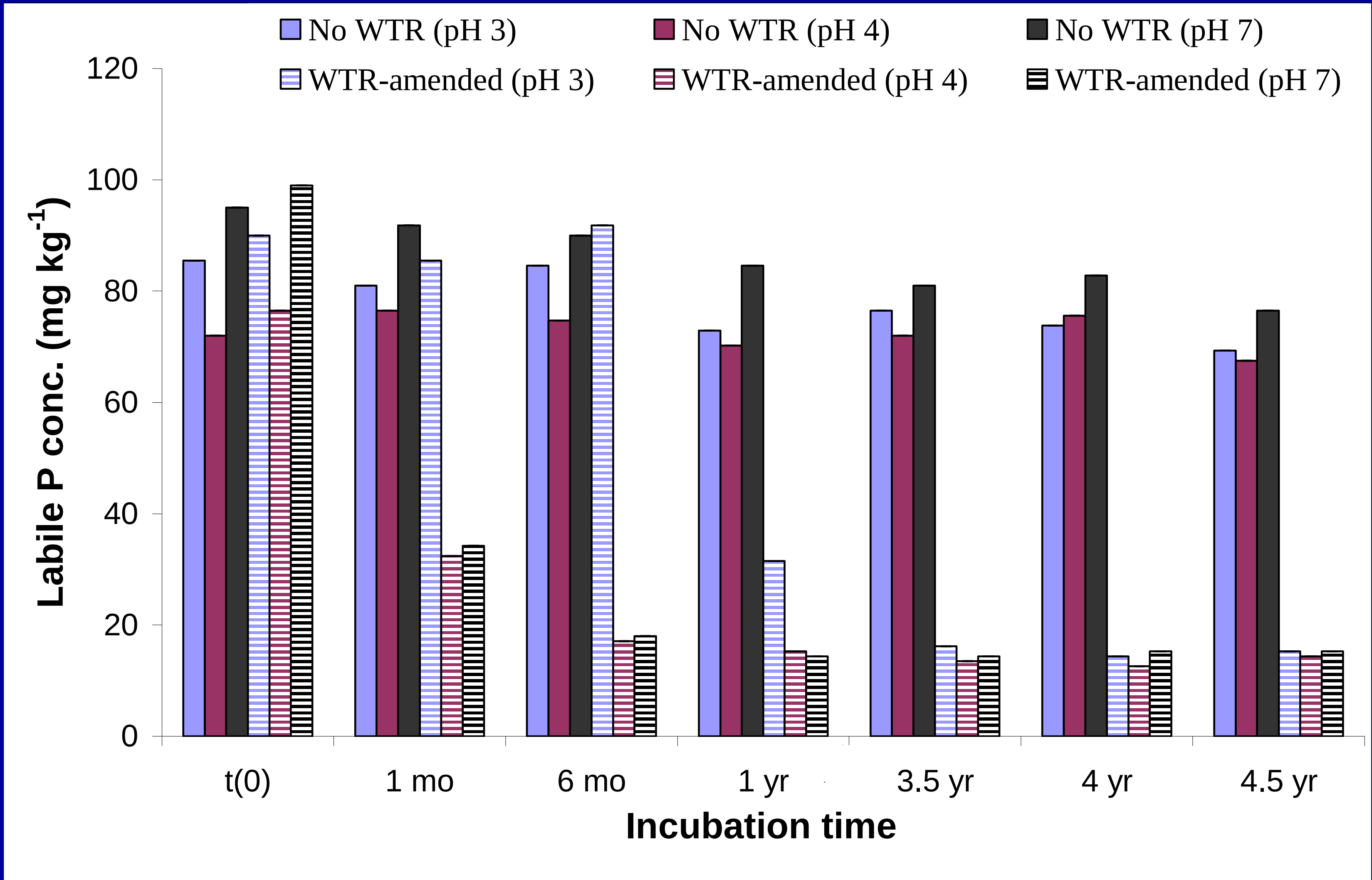
Agyin-Birikorang et al., 2008

WTR research and case studies



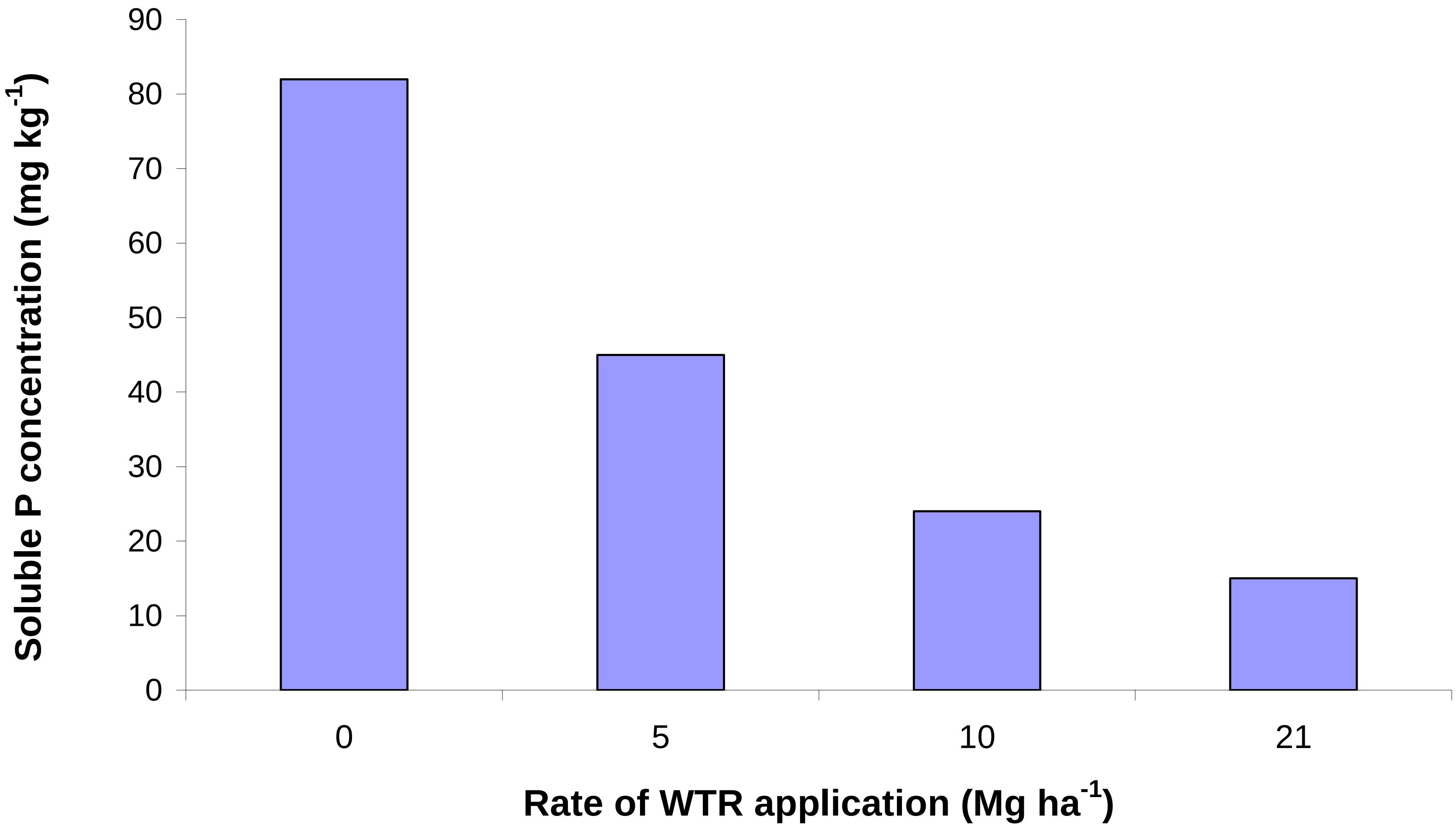
Agyin-Birikorang et al., 2009

Evidence of long-term stability



Agyin-Birikorang and O'Connor, 2007

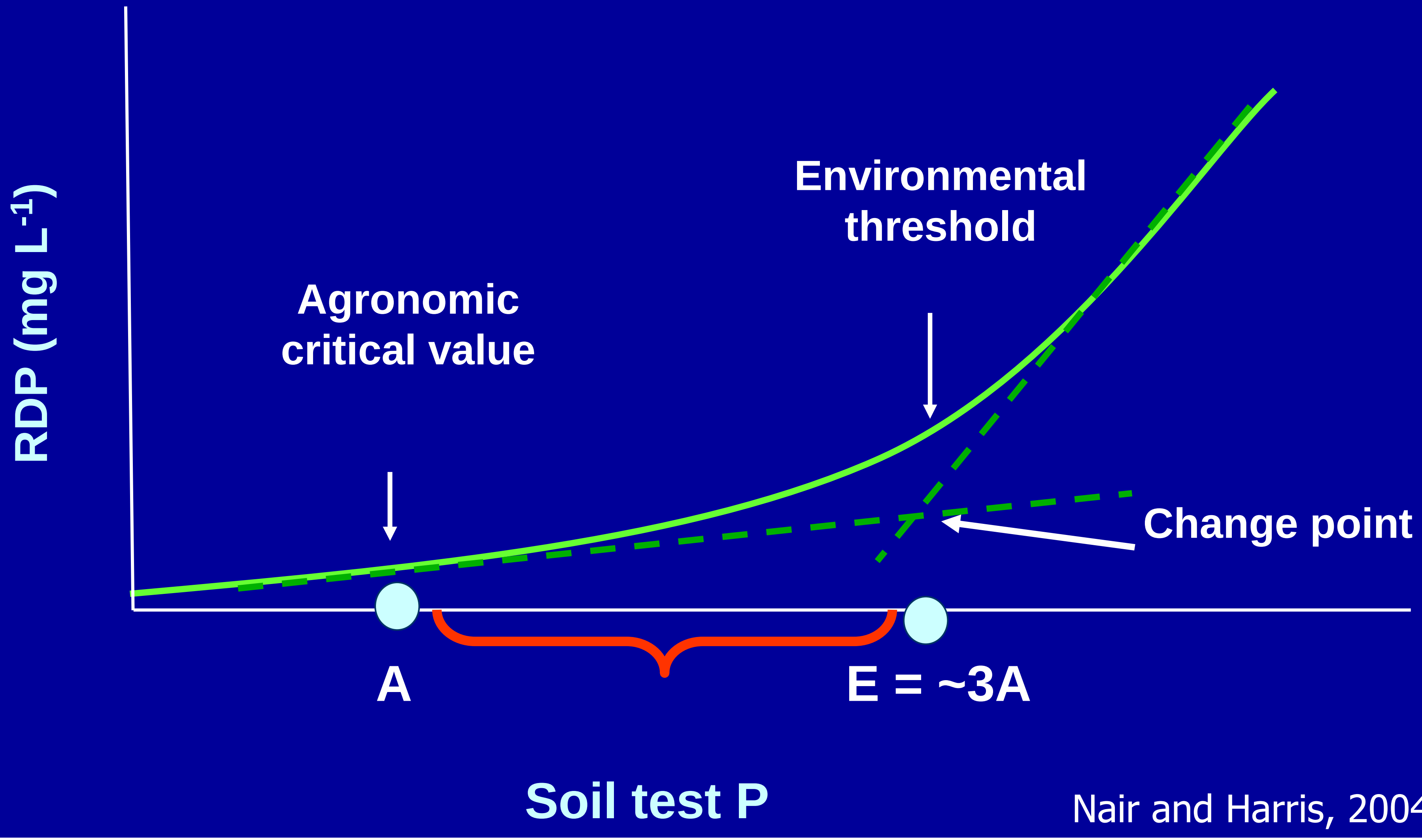
Evidence of long-term stability



Bayley et al., 2008

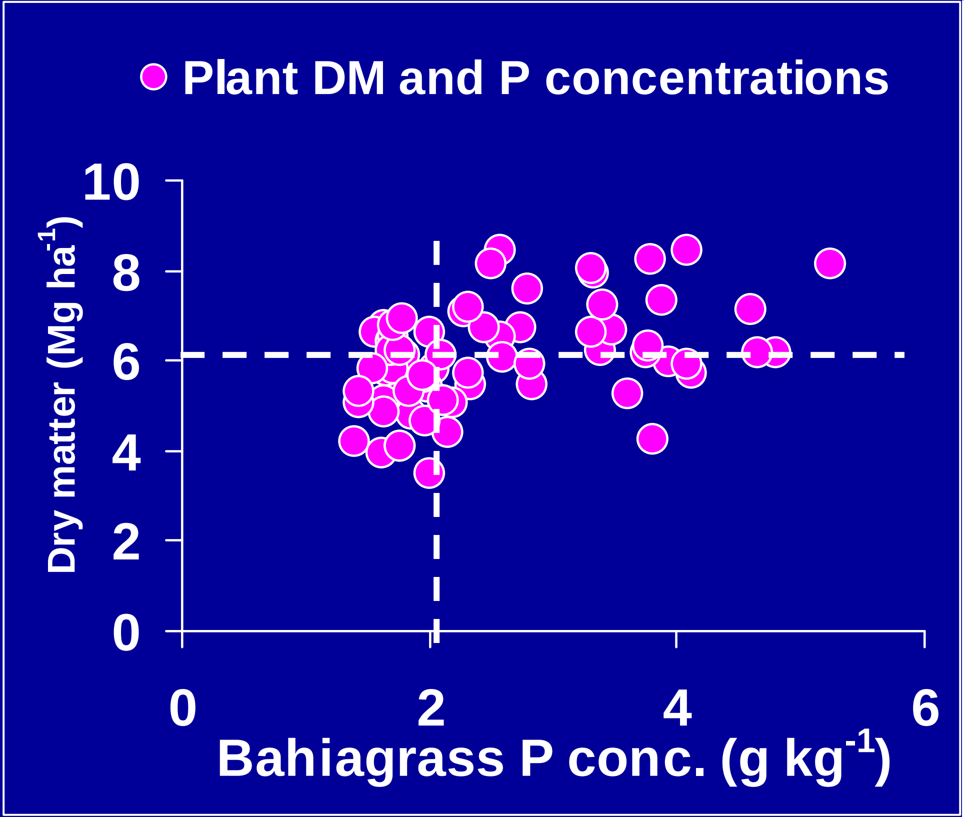
Issues:

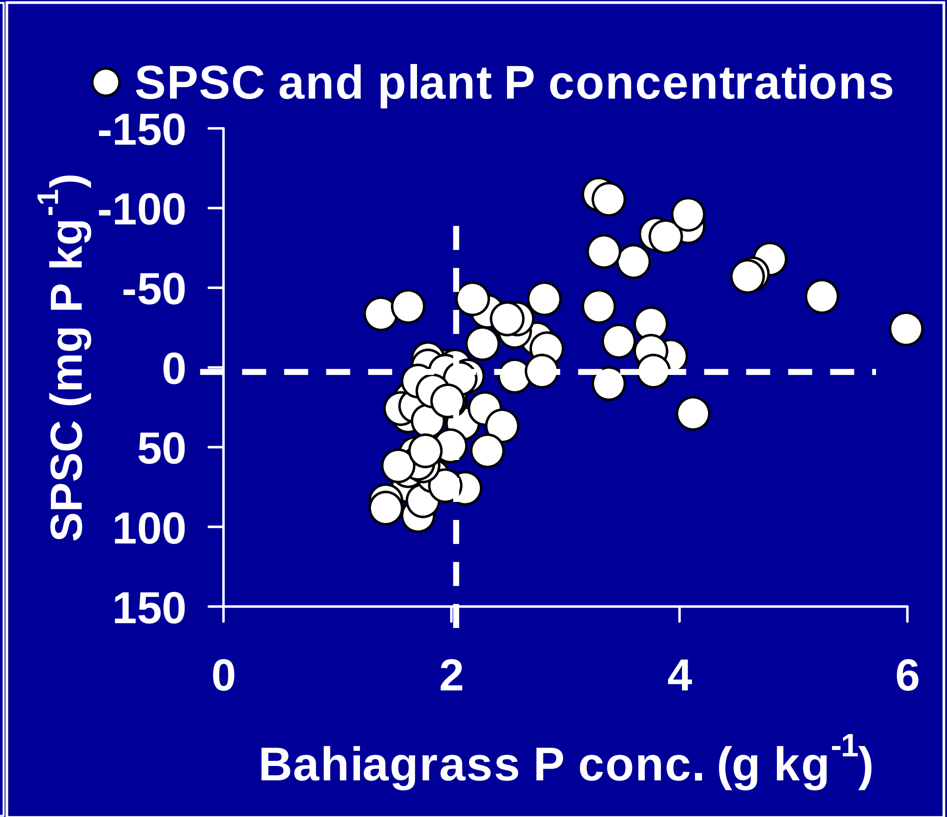
How much WTR to apply?



Nair and Harris, 2004

How Much WTR?





Oladeji, 2006

How Much WTR? (SPSC based)

$$SPSC\ (mg\ P\ kg^{-1}) = (0.15 - PSI)*(Al_{ox} + Fe_{ox})*31$$

where PSI = $[(P_{ox})/(Al_{ox} + Fe_{ox})]$

SPSC < 0: highly P-impacted soils
SPSC > 0: less P-impacted soils, but P deficient
SPSC = 0: agronomic and environmentally "safe"

$$SPSC_{soil} * Mass_{soil} + APSC_{source} * Mass_{source} + APSC_{WTR} * Mass_{WTR} = 0$$

$Mass_{WTR}$ is the only unknown variable

Oladeji et al., 2007

FL Concerns about WTR Use: Trace element loads

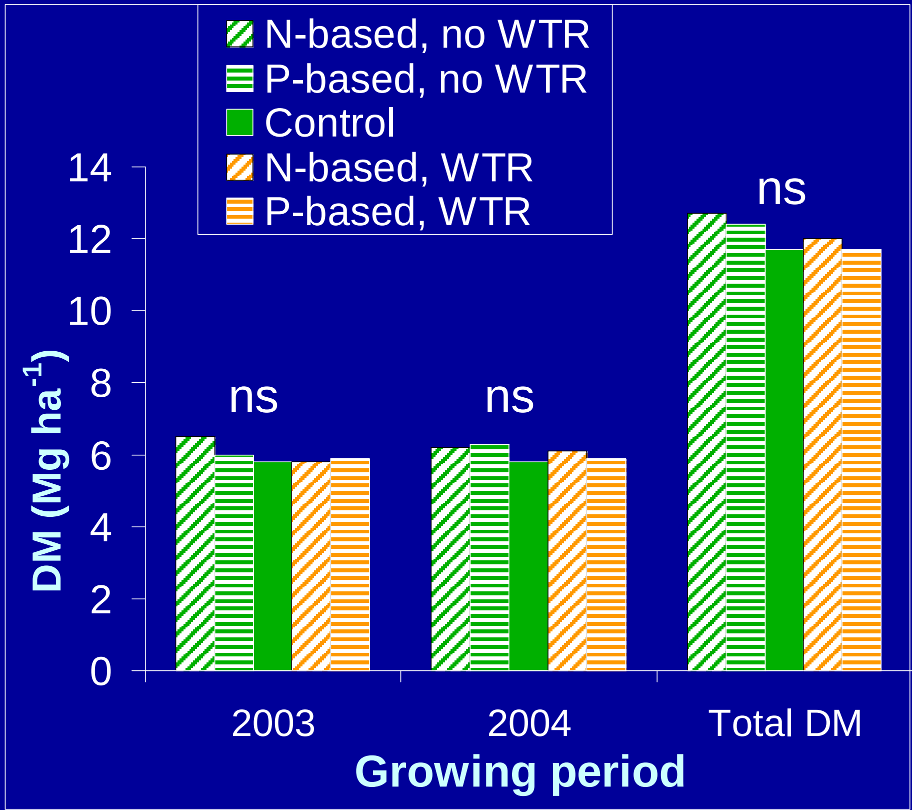
Total Al concentration (104-176 g kg^{-1}) > SCTL (7.2 g kg^{-1})

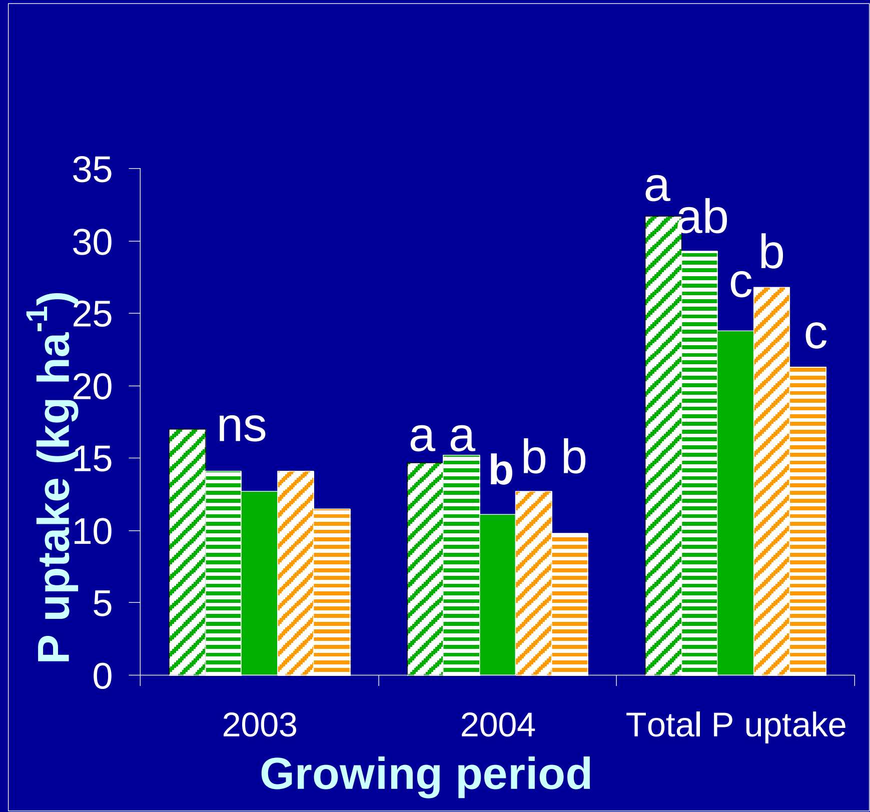
- Land application may result in:
  1. P deficiency
  2. Al phytotoxicity
  3. Al contamination of groundwater
  4. Animal toxicity

Total As > residential exposure limits (2.1 mg kg^{-1})

- Human exposure to As

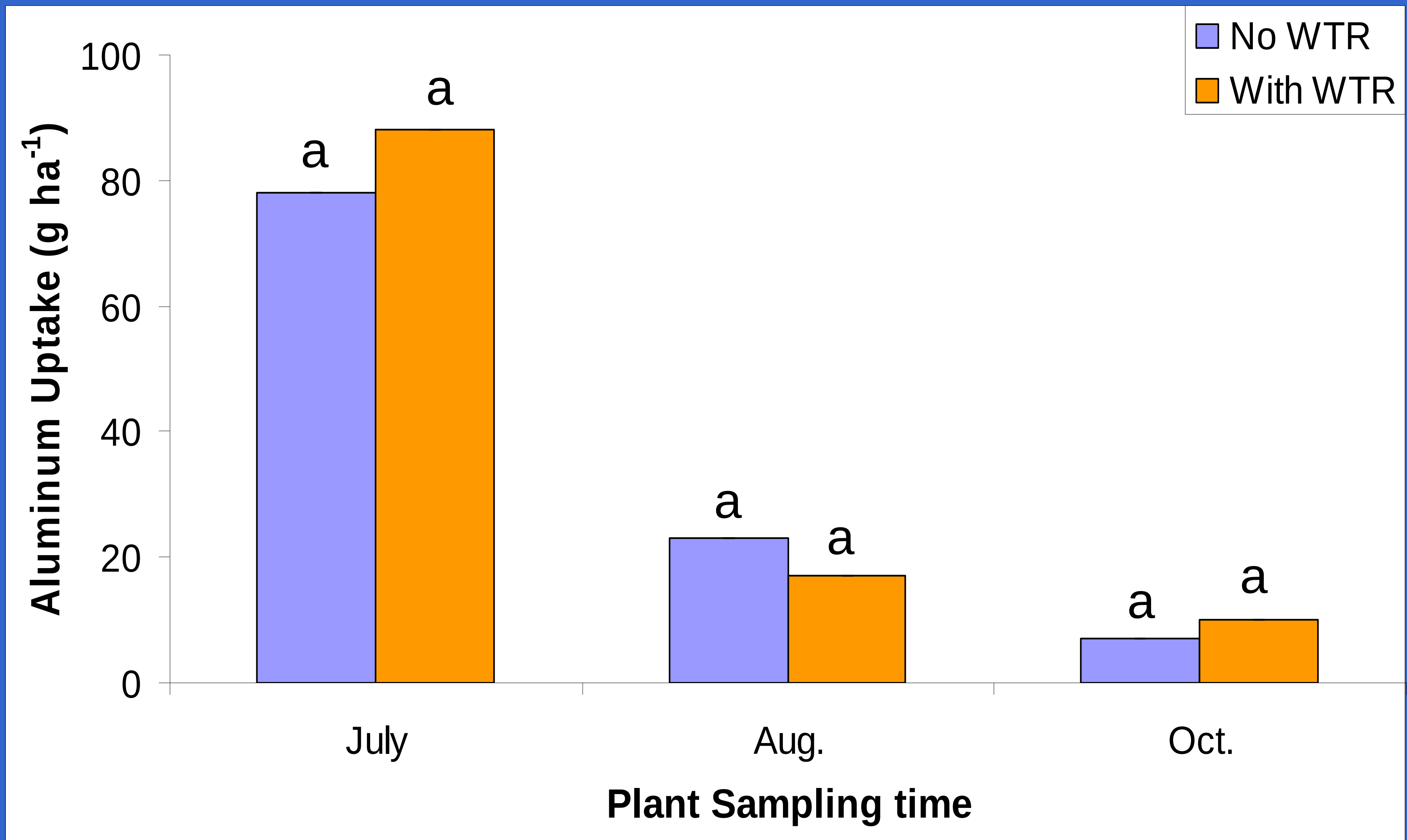
DM Yield and P Uptake





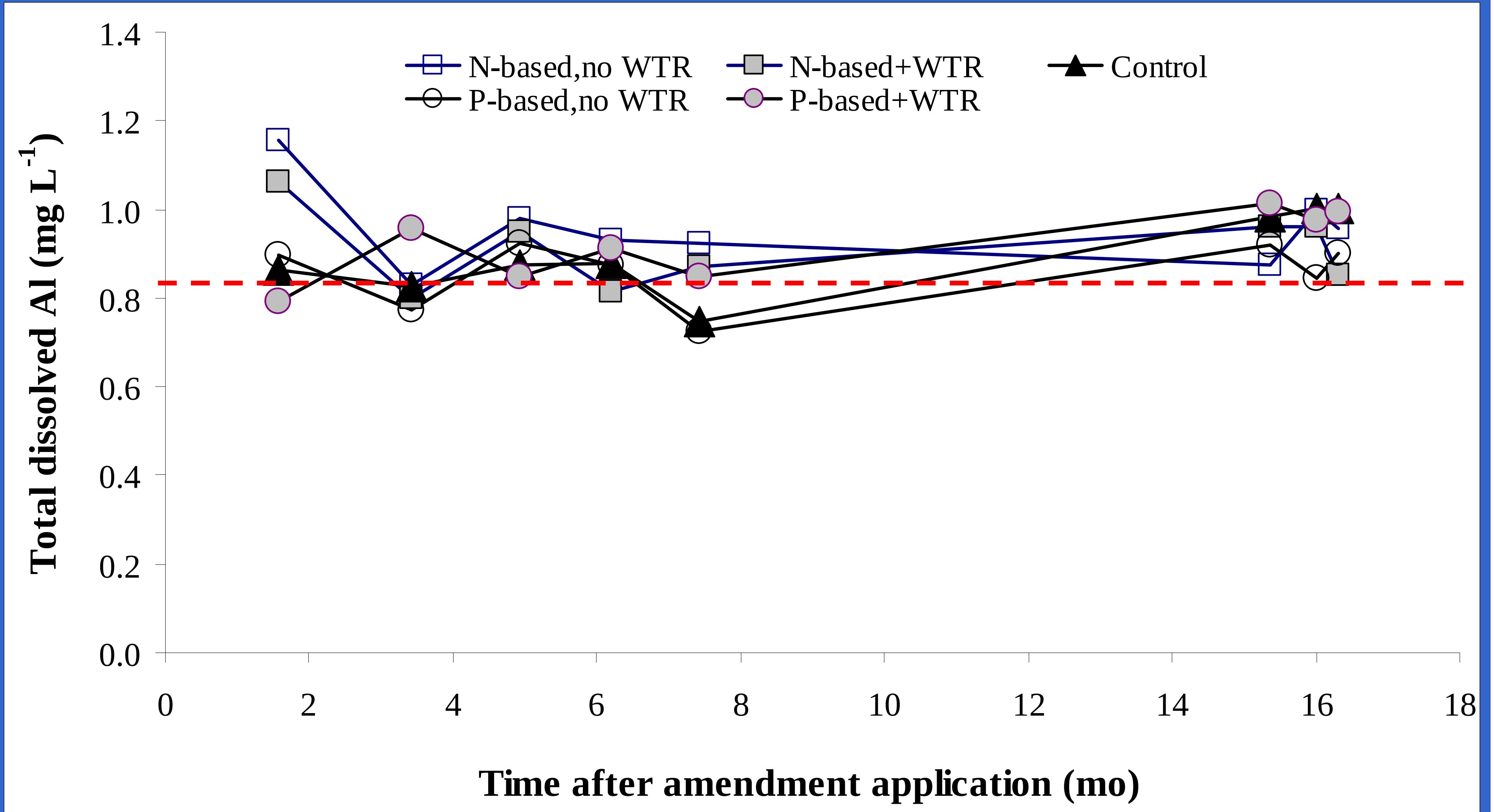
Oladeji et al., 2009

Plant Al Uptake



Oladeji et al., 2009

Shallow Groundwater Al



Agyin-Birikorang et al., 2009

Animal Effects: Grazing Cattle

- Duration of study: 2 y
- Cumulative Rate: 76 Mg WTR ha^{-1}
- No effects on liver, bone, and plasma Al, P, Ca, Mg, K, and Zn concentrations
- No effects on growth and development

Madison et al., 2009

Soil As Considerations

Soil Depth	App. Method	WTR Rate (%)	Added Soil As (mg kg^{-1})
1 cm	surface applied	1	1.8
1 cm	surface applied	2.5	4.5
5 cm	surface applied	1	0.4
5 cm	surface applied	2.5	0.9
15 cm	incorporated	1	0.1
15 cm	incorporated	2.5	0.3

Residential exposure limits = 2.1 mg kg^{-1}

Industrial exposure limits = 21 mg kg^{-1}

Lessons Learned

- Know WTR characteristics
  - Oxalate extractable Fe/Al content
  - Other constituents (e.g. trace elements)

- New P additions control
  - Surface apply WTR
  - Co-apply with P sources
  - Match rate to P additions and SPSC

- Legacy P control
  - Incorporate WTR
  - "Hot spots"
    - Permeable Reactive Barriers

References

- Agyin-Birikorang, S., and G.A. O'Connor 2007. Lability of drinking-water treatment residuals (WTR) immobilized phosphorus: Aging and pH effects. J. Environ. Qual. 36:1076-1085.
- Agyin-Birikorang, S., G.A. O'Connor, O.O. Oladeji, T.A. Obreza, J.C. Capece. 2008. Drinking-water treatment residuals (WTR) effects on the phosphorus status of field soils amended with biosolids, manure, and fertilizer. Commun. Soil Sci. Plant Anal. 39:1700-1719.
- Agyin-Birikorang, S., G.A. O'Connor, and T.A. Obreza. 2009. Are alum-based drinking water treatment residuals safe for land application? Extension letter SL 299 Univ. of Florida, 8 pp.
- Agyin-Birikorang, S., O.O. Oladeji, G.A. O'Connor, T.A. Obreza, and J.C. Capece. 2009. Efficacy of drinking-water treatment residual in controlling off-site phosphorus losses: A field study in Florida J. Environ. Qual. 38:1076-1085.
- Bayley, R.M., J.A. Ippolito, M.E. Stromberger, K.A. Barbarick, and M.W. Paschke. 2008. Water treatment residuals and biosolids coapplications affect semiarid rangeland phosphorus cycling. Soil Sci. Soc. Am. J. 72:711-719.
- Dayton, E.A., and N.T. Basta. 2005. Use of drinking water treatment residuals as a potential best management practice to reduce phosphorus risk index scores. J. Environ. Qual. 34: 2112-2117.
- Elliott, H.A., G.A. O'Connor, P. Lu, and S. Brinton. 2002. Influence of water treatment residuals on phosphorus solubility and leaching. J. Environ. Qual. 31:1362-1369.
- Harper, H.H., J.L. Herr, and E.H. Livingston. 1998. "Alum Treatment of Stormwater: The First Ten Years." New Applications in Modeling Urban Water Systems - Monograph 7 - Proceedings of the Conference on Stormwater and Related Modeling: Management and Impacts, Toronto, Canada, February 19-20.
- Madison, R.K., L.R. McDowell, G.A. O'Connor, N.S. Wilkinson, P.A. Davis, A.T. Adesogan, T.L. Felix, and Brennan M. 2009. Effects of aluminum from water-treatment-residual applications to pastures on mineral status of grazing cattle and mineral concentrations of forages. Commun. Soil Sci. Plant Anal. 40:3077-3103.
- Maguire,R.O., J.T. Sims, S.K. Dentel, F.J. Coale, and J.T. Mah. 2001. Relationships between biosolids treatment process and soil phosphorus availability. J. Environ. Qual. 30:1023-1033.
- Makris, K.C., 2004. Long-term stability of sorbed phosphorus by drinking water treatment residuals: mechanisms and implications. PhD diss. Univ. Florida. Gainesville, FL.
- Makris, K.C., and G.A. O'Connor. 2007 Beneficial utilization of drinking-water treatment residuals as contaminant-mitigating agents. In: D. Sarkar et al. (Eds). Developments in Environmental Science, Vol. 5: Concepts and Applications in Environmental Geochemistry, Elsevier Sci. Amsterdam, pp.607-636.
- Nair, V.D., and W.G. Harris. 2004. A capacity factor as an alternative to soil test phosphorus in phosphorus risk assessment. New Zealand J. Agri. Res. 47:491-497.
- O'Connor, G.A., S. Brinton, and M.L. Silveira 2005. Evaluation and selection of soil amendments for field testing to reduce P losses. Soil Crop Sci. Soc. FL. Proc. 64:22-34.
- Oladeji, O.O., 2006. Management of phosphorus sources and water treatment residuals (WTR) for environmental and agronomic benefits. PhD diss. Univ. Florida. Gainesville, FL.
- Oladeji, O.O., G.A. O'Connor, J.B. Sartain, and V.D. Nair., 2007. Controlled application rate of water treatment residual for agronomic and environmental benefits. J. Environ. Qual. 36:1715-1724.
- Oladeji, O.O., J.B. Sartain, and G.A. O'Connor, 2009. Land application of aluminum water treatment residual: Aluminum phytoavailability and forage yield. Commun. Soil Sci. Plant Anal. 40:1483-1498
- Silveira, M.L., M.K. Miyattah, and G.A. O'Connor. 2006. Phosphorus release from a manure-impacted Spodosol: Effects of a water treatment residual. J. Environ. Qual. 35:529-541.
- Smith, D.R., P.A. Moore, C.L. Griffis, T.C. Daniel, D.R. Edwards, and D.L.Boothe. 2001. Effects of alum and aluminum chloride on phosphorus runoff from swine manure. J. Environ. Qual. 30:992-998.
- Wanielista, M., D. Bottcher, T. DeBusk, H. Harper, S. Iwinski, and G.A. O'Connor. 2009. Technical assistance for the northern Everglades chemical treatment pilot project. SFWMD Project ID#: PS 100093, July 6, 2009.

Thank You!

O'Connor
gao@ufl.edu

Elliott
hae1@psu.edu

Agyin-Birikorang
agyin@ufl.edu