# Phosphorus Availability from Organic Residuals

## UMass Extension Symposium: Managing Phosphorus in Organic Residuals Applied to Soils

November 2, 2016

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# Topics for Discussion

- Survey of P in organic residuals
- Chemical speciation of P in residuals
- Fate of residual P in agricultural soils
  - Surface applied residuals
  - Incorporated/injected residuals
- Phosphorus dynamics following application of residuals

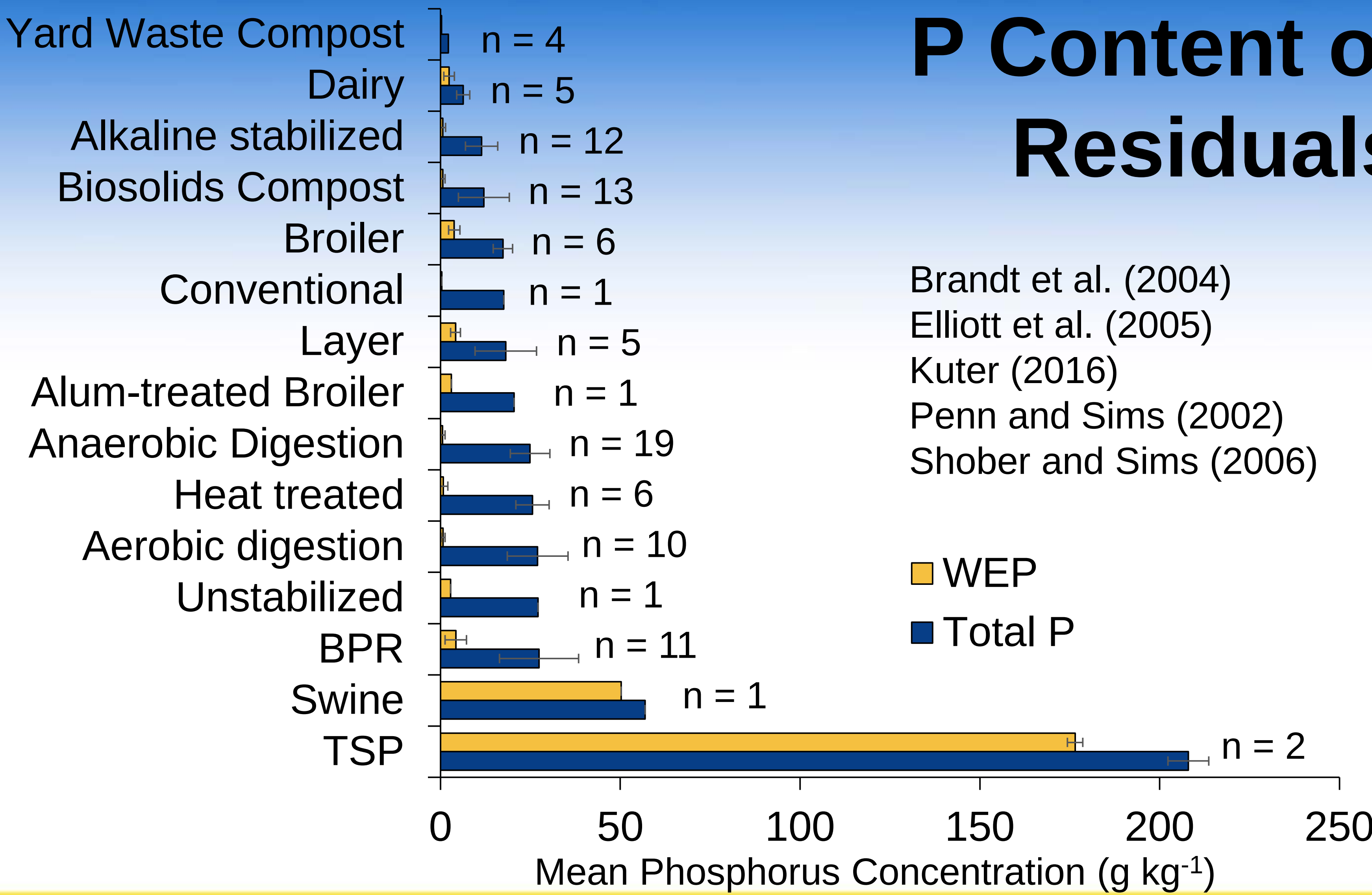
Managing Phosphorus in Organic Residuals Applied to Soils

# SURVEY OF PHOSPHORUS IN RESIDUALS

# What Do We Know About Phosphorus in Residuals?

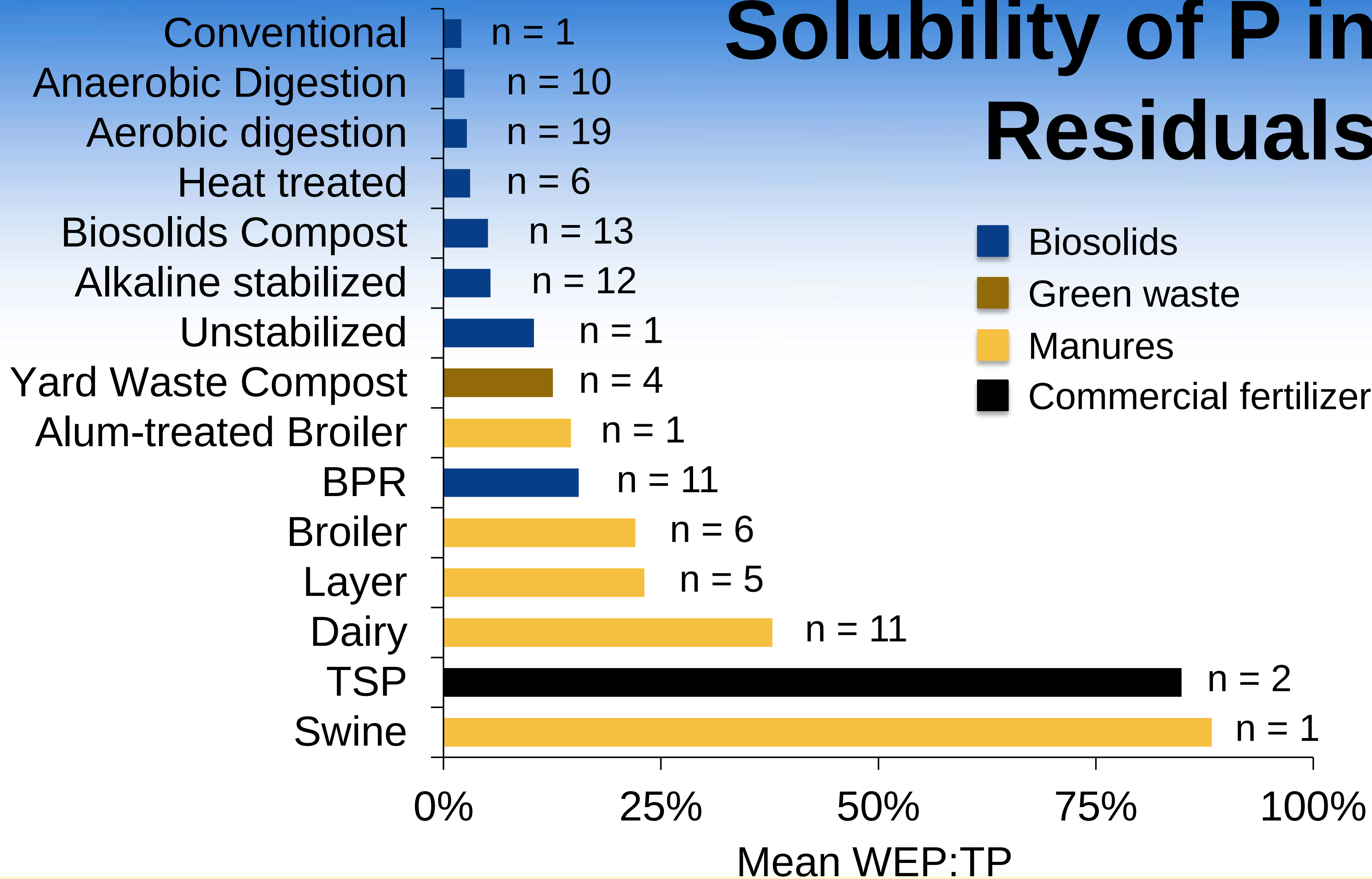
- Wet chemical analysis provide some evidence of chemical “forms”
  - Examples:
    - EPA 3050 digestion (“Total” elements)
    - Water extractable P (WEP)
    - Sequential chemical fractionation (Operational fractions)
- Requires sample destruction

# P Content of Residuals

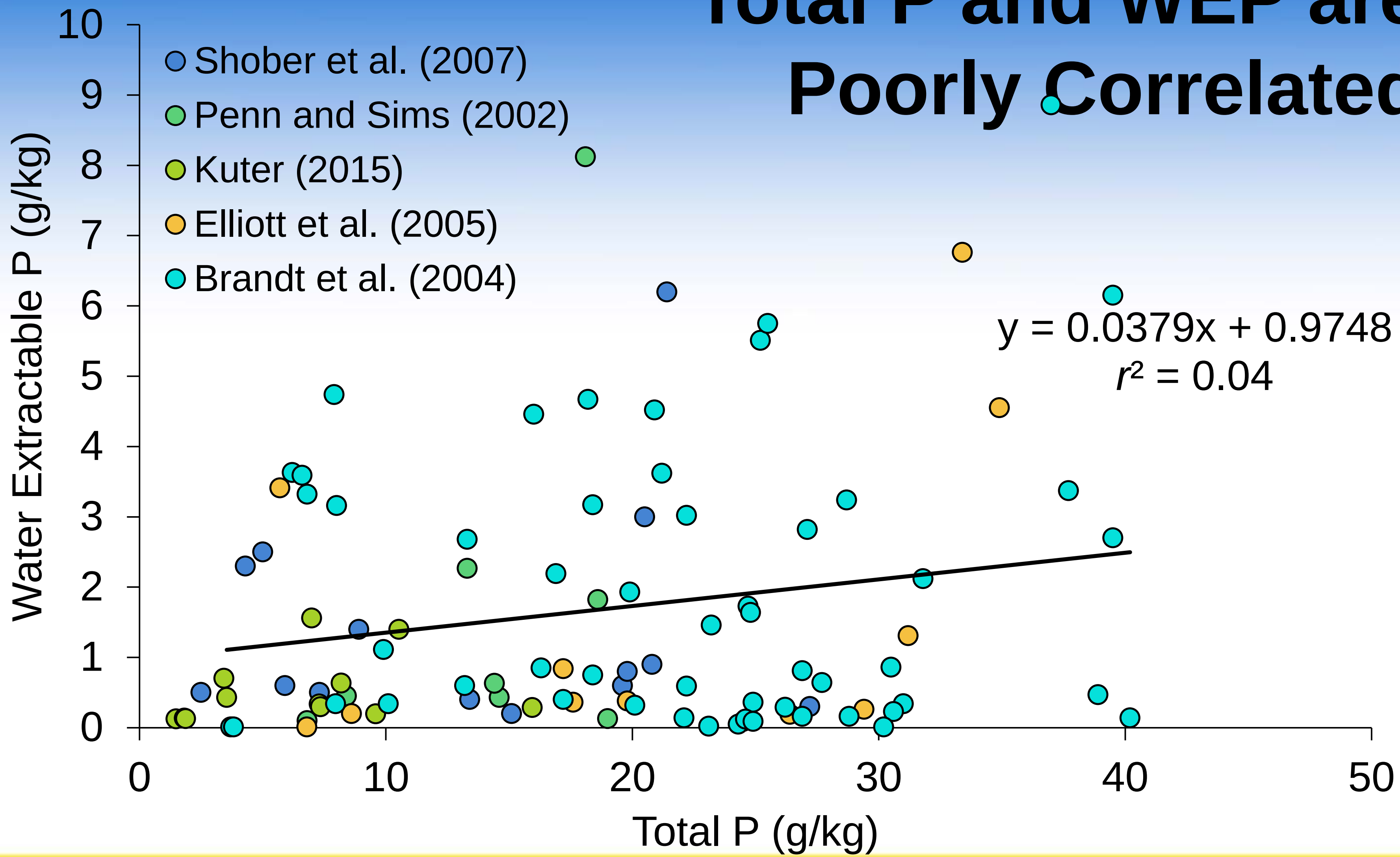



Brandt et al. (2004)
Elliott et al. (2005)
Kuter (2016)
Penn and Sims (2002)
Shober and Sims (2006)

# Solubility of P in Residuals



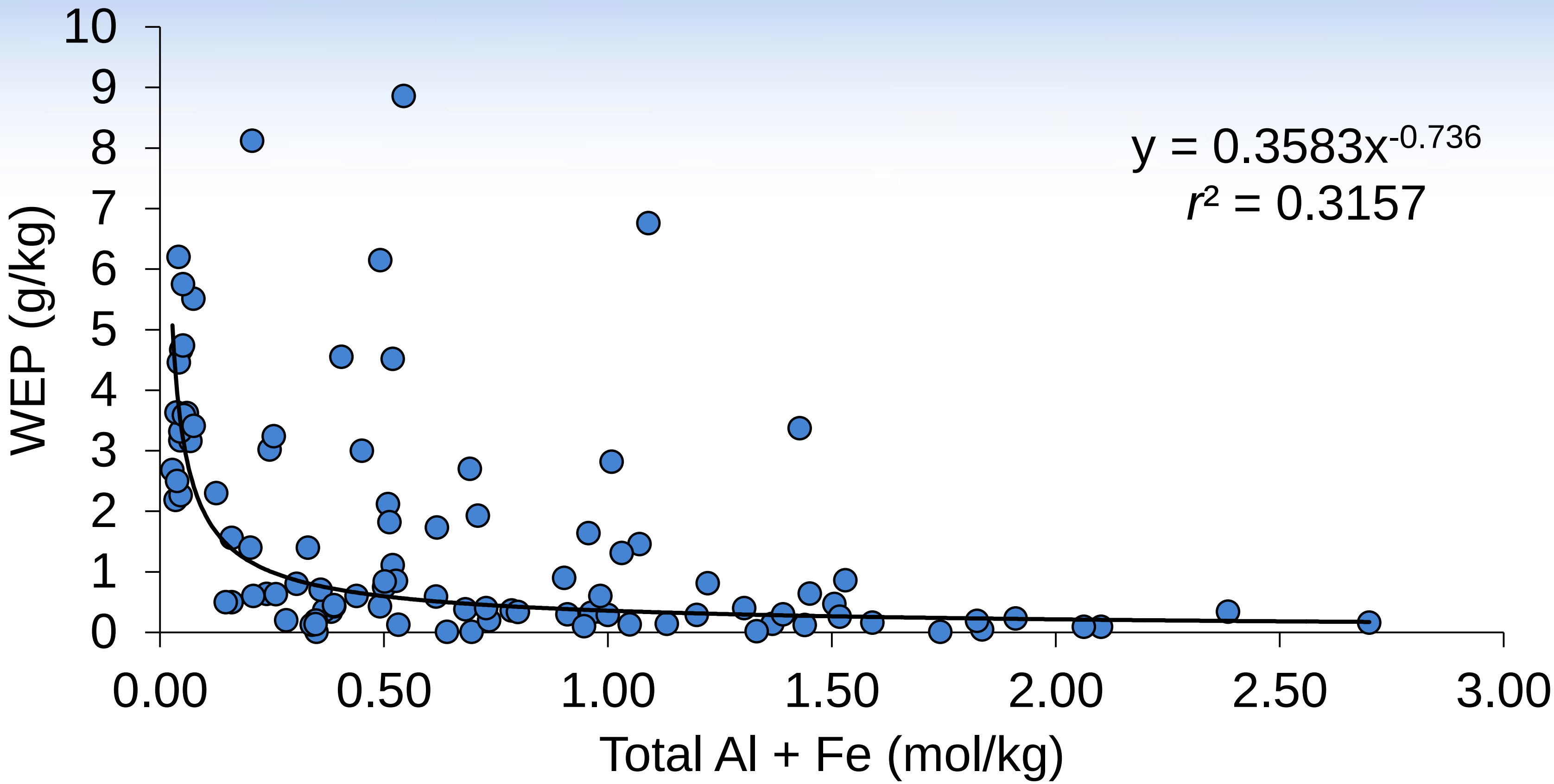
# Total P and WEP are Poorly Correlated



# What Factors Affect P Solubility?

1. Chemical composition and treatment
2. Animal type and diet modification
3. Storage of materials (wet vs. dry)


# Other Chemical Properties Control Phosphorus Solubility

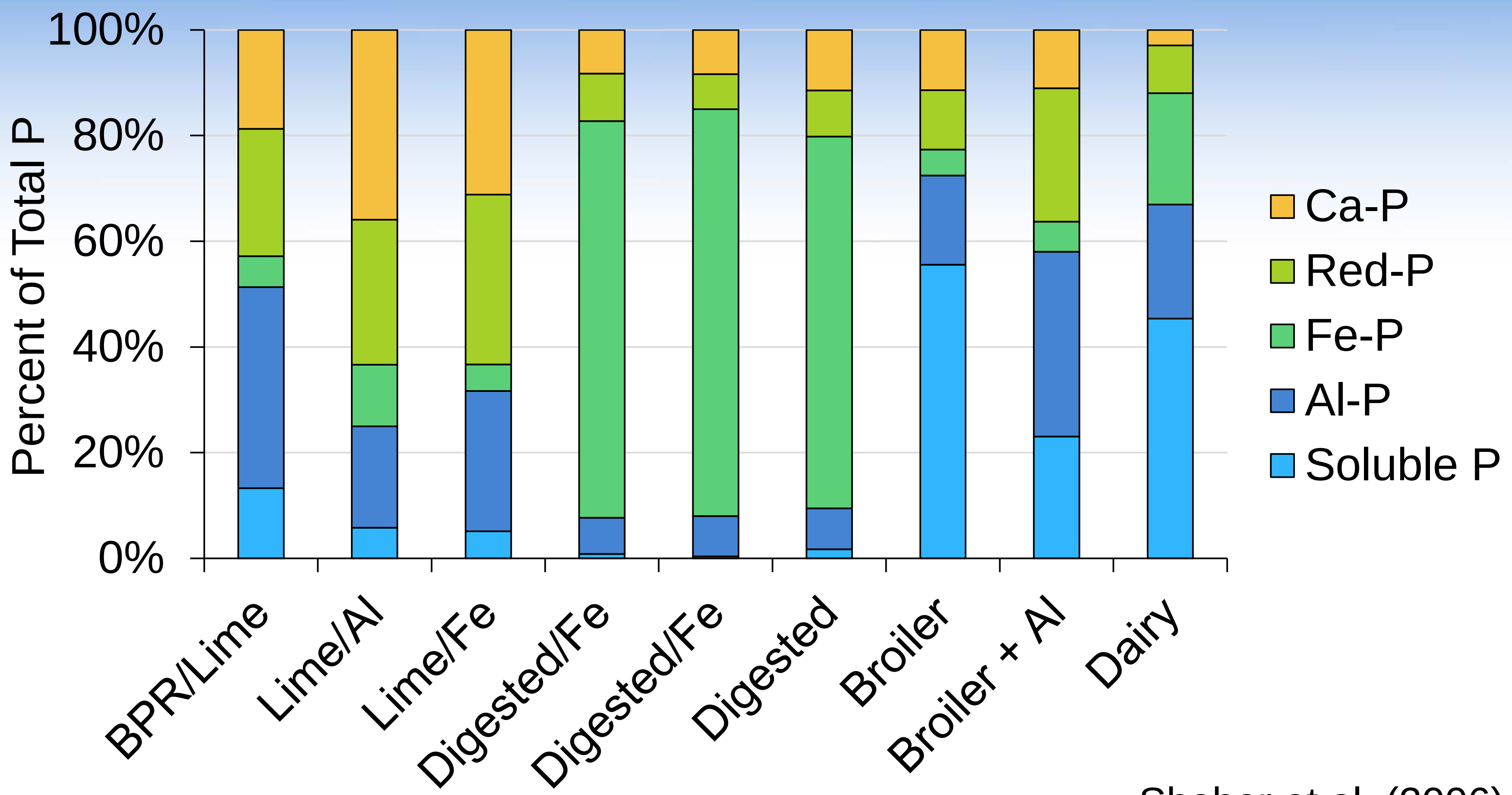


Shober et al. (2006)

# Chemical Properties of Residuals

| Source | Treatment | Solids | WEP | P | Al | Ca | Fe |
|---|---|---|---|---|---|---|---|
| | | % | ---------------- | ---------------- | g kg$^{-1}$ | ---------------- | ---------------- |
| | | Biosolids | | | | | |
| BPR | Lime | 31 | 0.82 | 17.8 | 5.84 | 78.5 | 4.12 |
| Alkaline stabilization | Al | 21 | 0.21 | 12.6 | 9.78 | 196 | 19.0 |
| Alkaline stabilization | Fe | 30 | 0.42 | 13.7 | 5.11 | 126 | 36.3 |
| Anaerobic digestion | Fe | 20 | 0.58 | 30.1 | 13.7 | 14.5 | 56.0 |
| Anaerobic digestion | Fe | 19 | 0.27 | 30.3 | 15.8 | 22.5 | 57.6 |
| Anaerobic digestion | None | 26 | 0.94 | 21.7 | 11.9 | 19 | 29.7 |
| | | Manures | | | | | |
| Broiler | None | 77 | 6.24 | 21.4 | 0.71 | 30.8 | 0.99 |
| Broiler + Alum | Al | 76 | 3.01 | 20.5 | 12.1 | 24.7 | 1.25 |
| Dairy | None | 18 | 2.32 | 4.30 | 0.87 | 73.6 | 2.12 |
| Dairy | None | 16 | 4.88 | 8.10 | 2.87 | 21.3 | 10.3 |

# Fractionation of P in Residuals

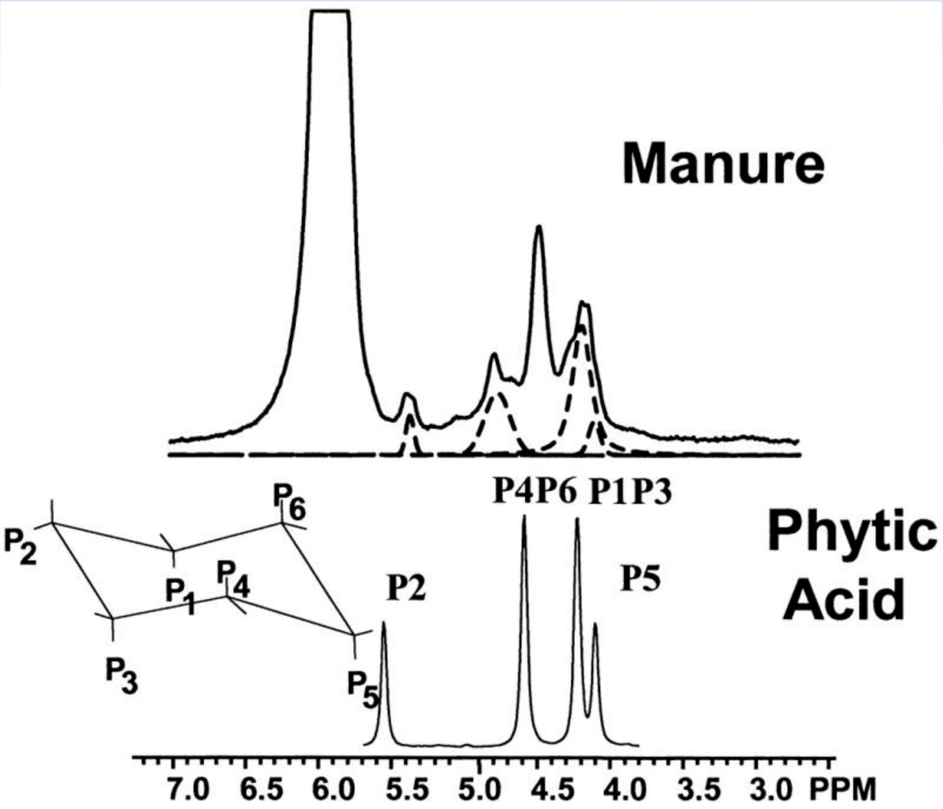



Shober et al. (2006)

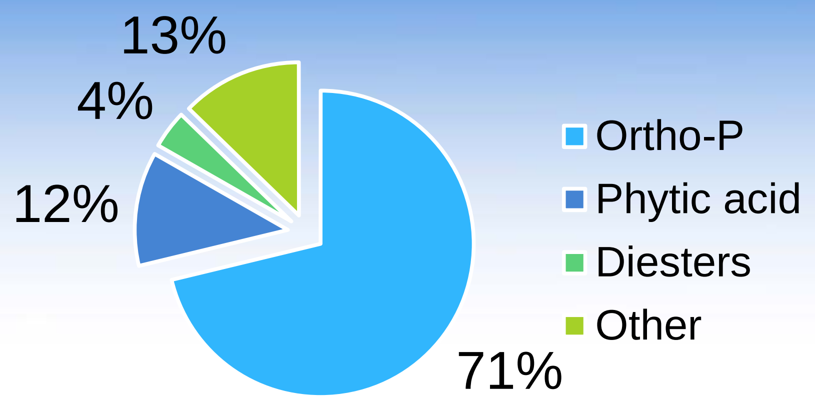
# Direct Speciation Techniques

- **X-ray Diffraction (XRD)**: ID crystalline minerals
- **Scanning Electron Microscopy (SEM) with X-ray elemental spectrometry (EDXS)**: Mapping of elemental components
- **$^{31}$P-Nuclear Magnetic Resonance (P-NMR)**: No ID of Fe-P species due to interference
- **X-ray Absorption Near Edge Structure Spectroscopy (XANES):** Limited access to facilities

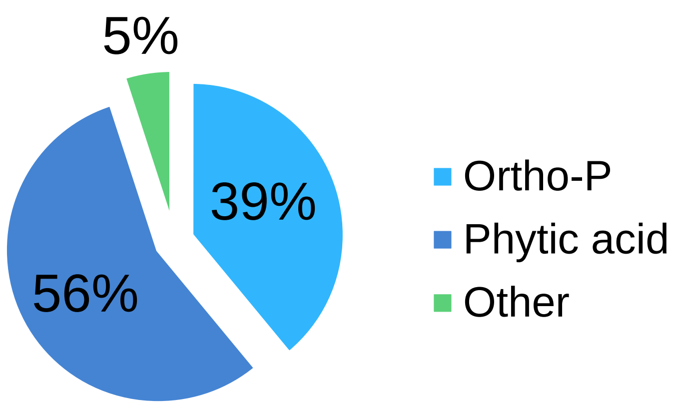
# $^{31}$P-NMR Analysis of Manure



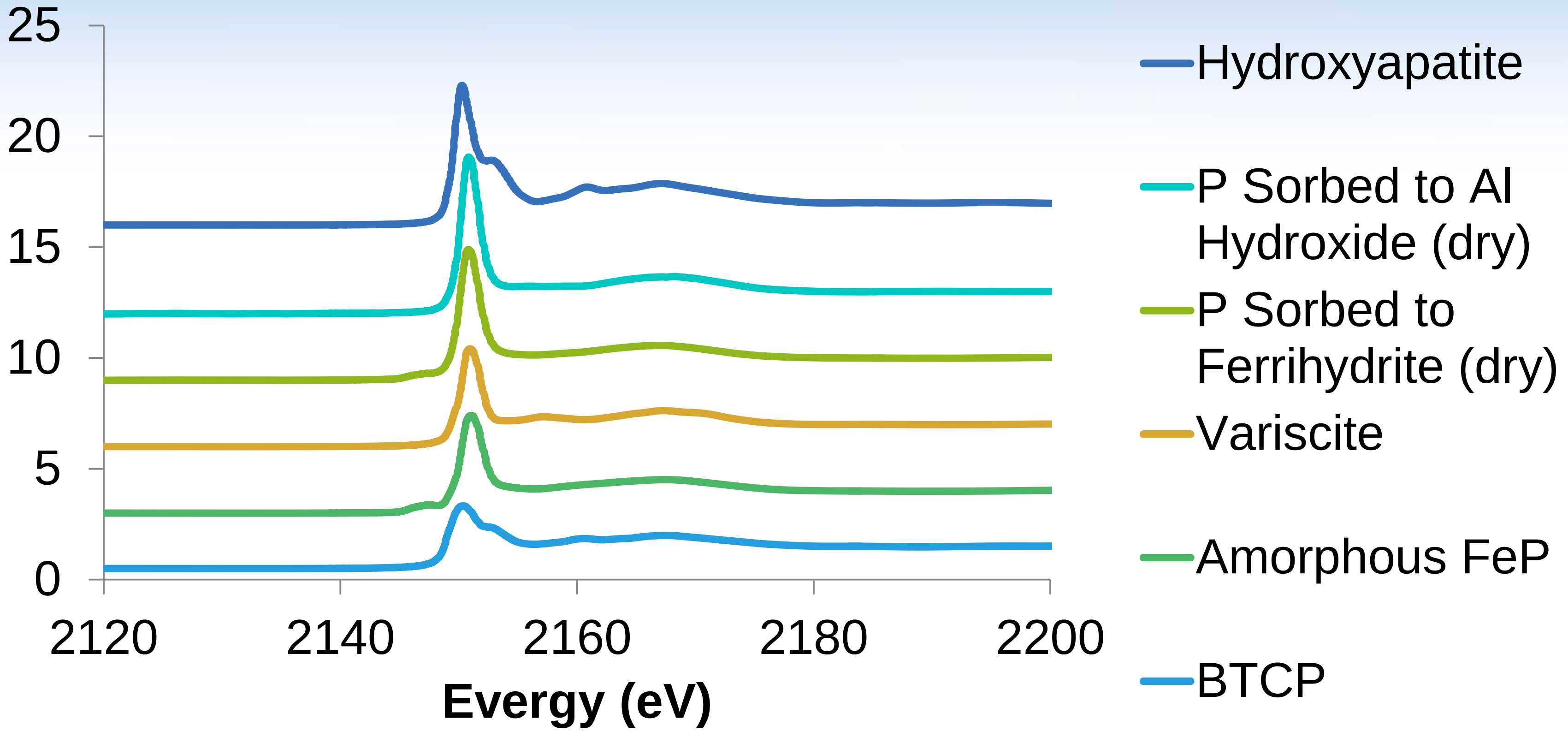

Dairy manure – Toor et al. (2005)




Broiler litter – McGrath et al. (2005)



# XANES Linear Combination Fitting With Known Standards

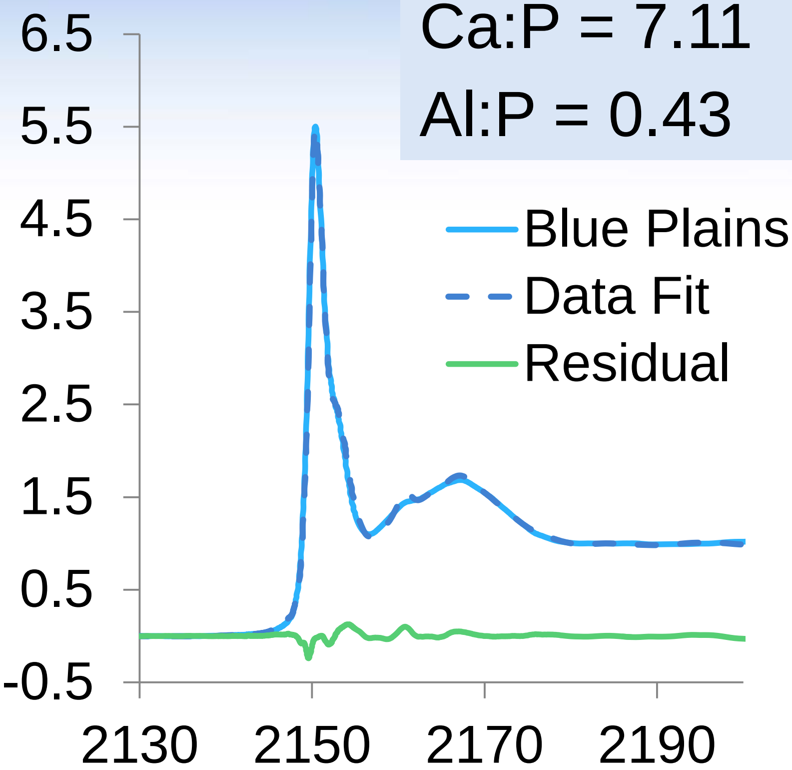


# XANES Speciation of Biosolids P

Fe:P = 1.47

Ca:P = 7.11

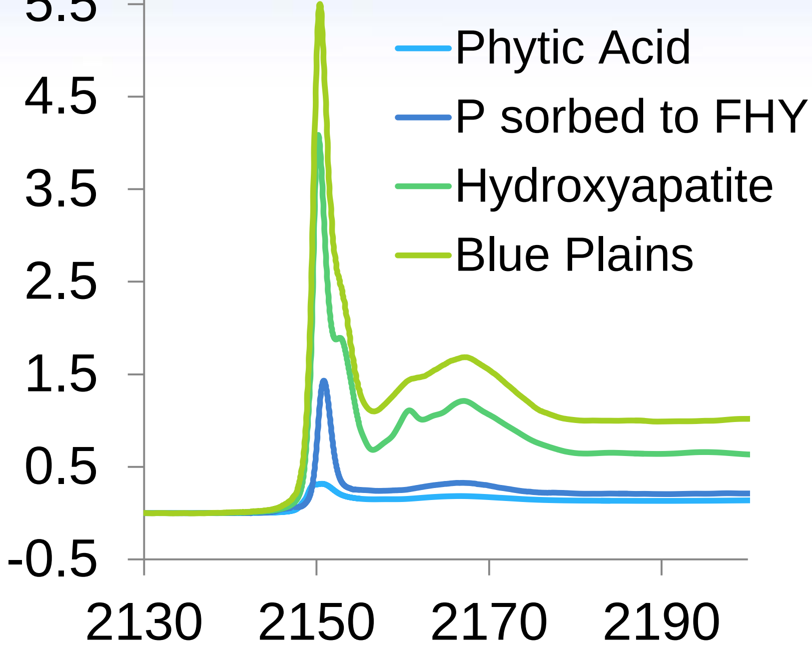
Al:P = 0.43




61% Hydroxylapatite

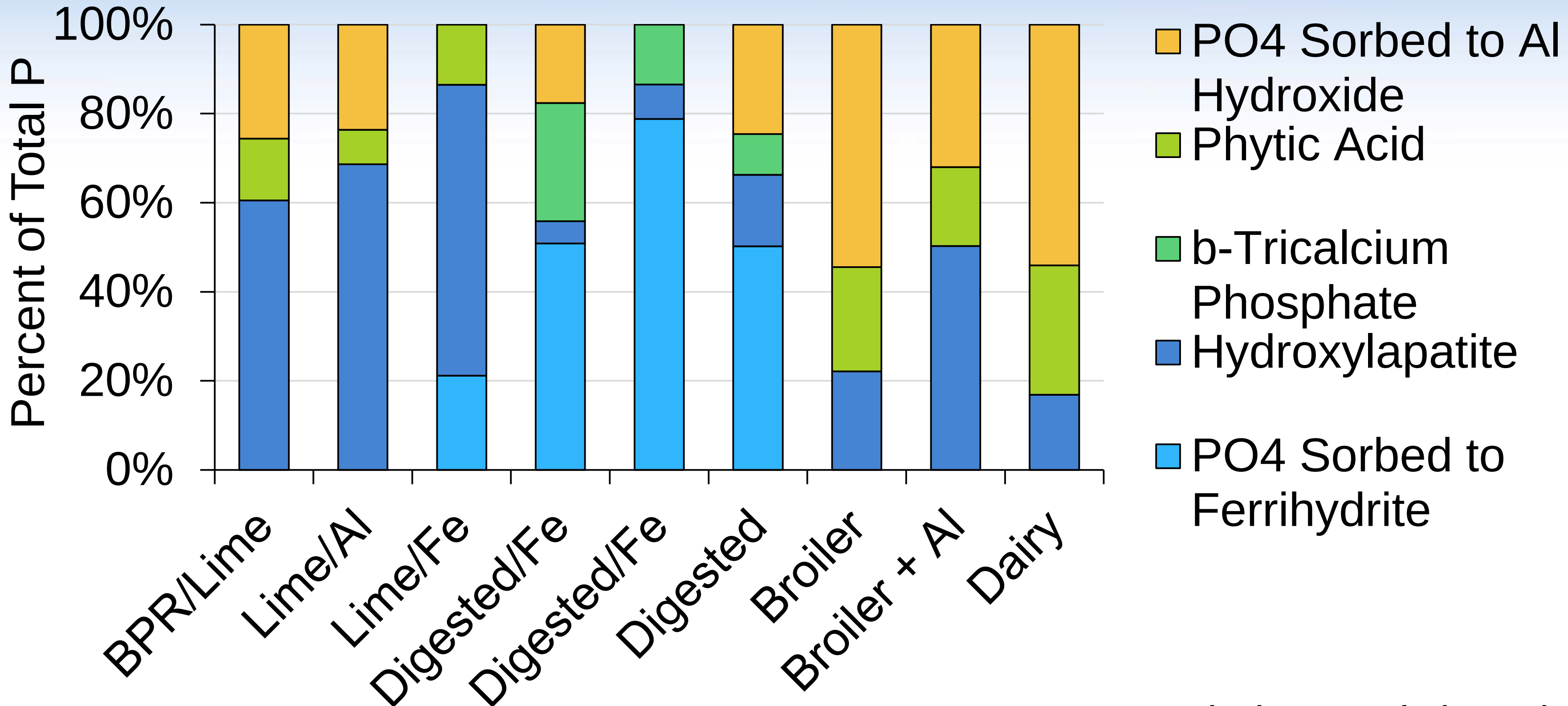
23% P Sorbed to Ferrihydrite

8% Phytic Acid (Na Salt)



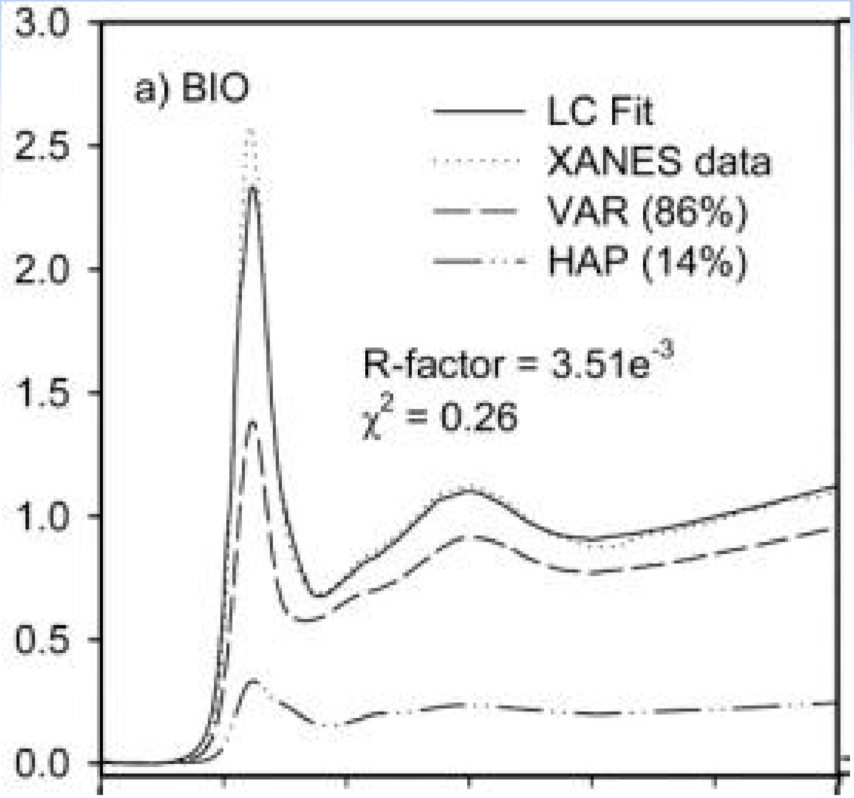

Energy (eV)

# XANES Speciation of Phosphorus




Shober et al. (2006)

# Other XANES Speciation Work



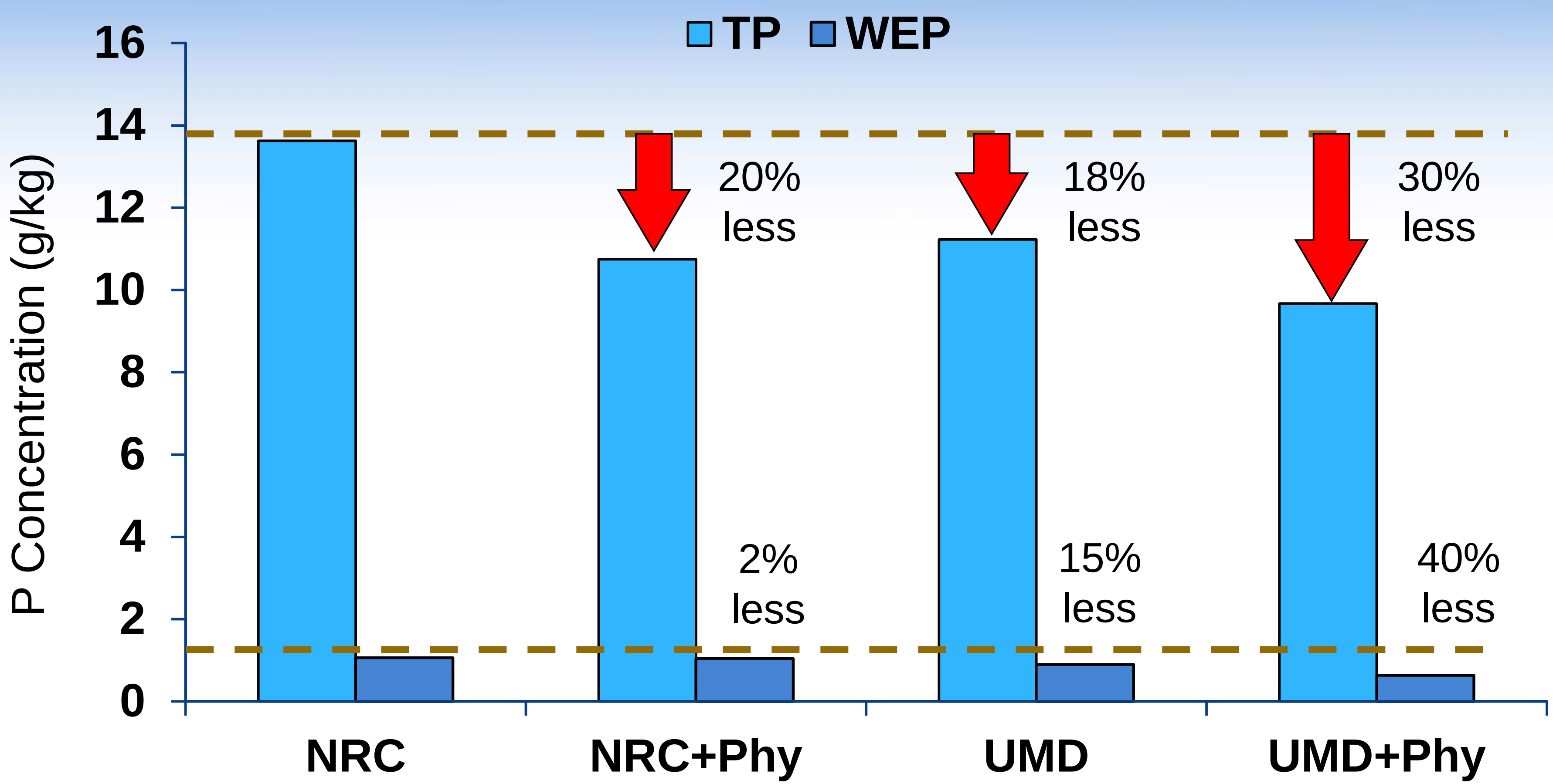

Digested biosolids - Ajiboye et al. (2007)

- 86% Variscite (Al-P)
- 14% Hydroxyapatite (Ca-P)

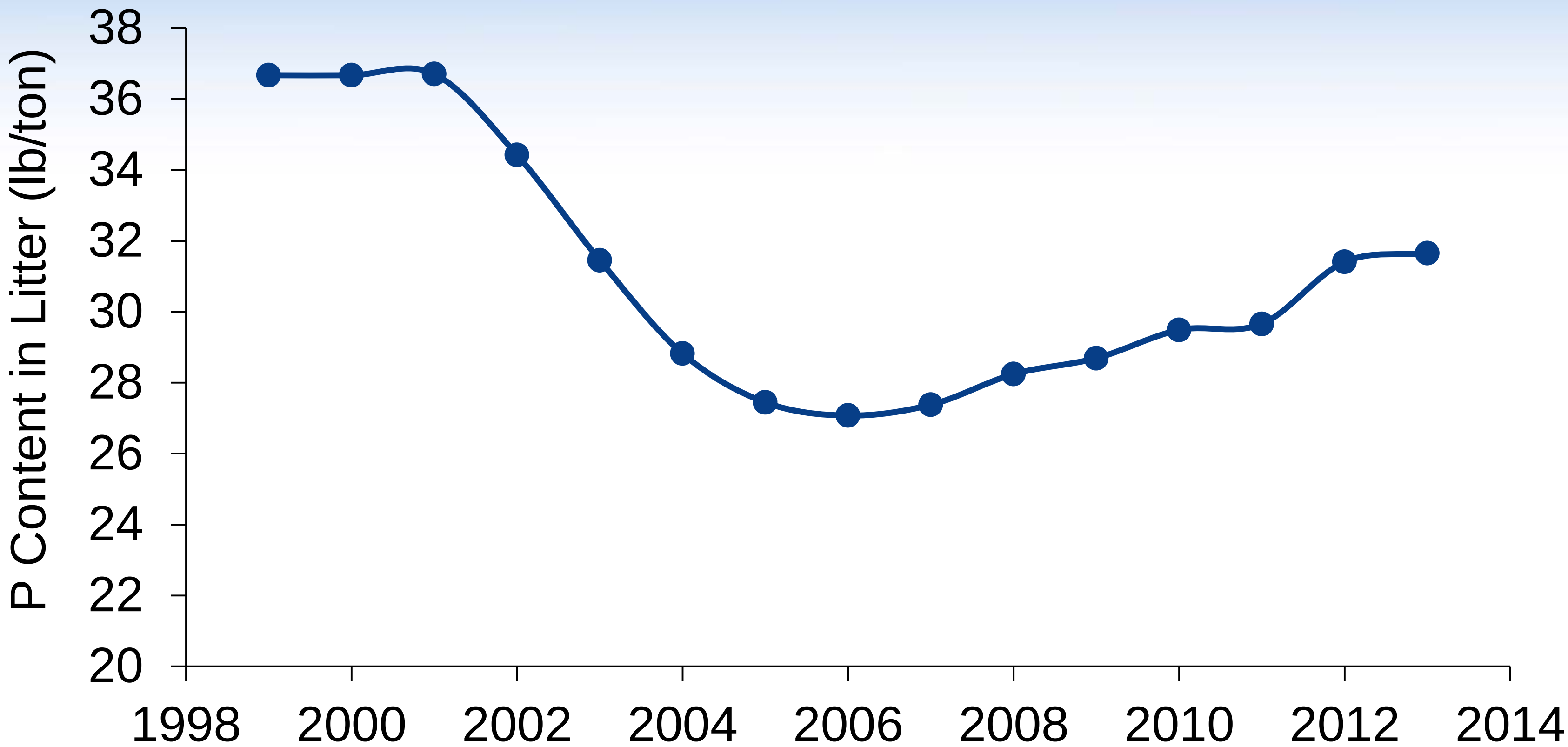
Broiler litter - Toor et al. (2005)

| | | Add phytase to diet |
|---|---|---|
| • | 15% aqueous P | 13% |
| • | 20% phytic acid | 7% |
| • | 65% dicalcium phosphate | 80% |

# Diet Affects Total P in Broiler Litter



# Industry Adoption of Phytase Reduced Manure P Load

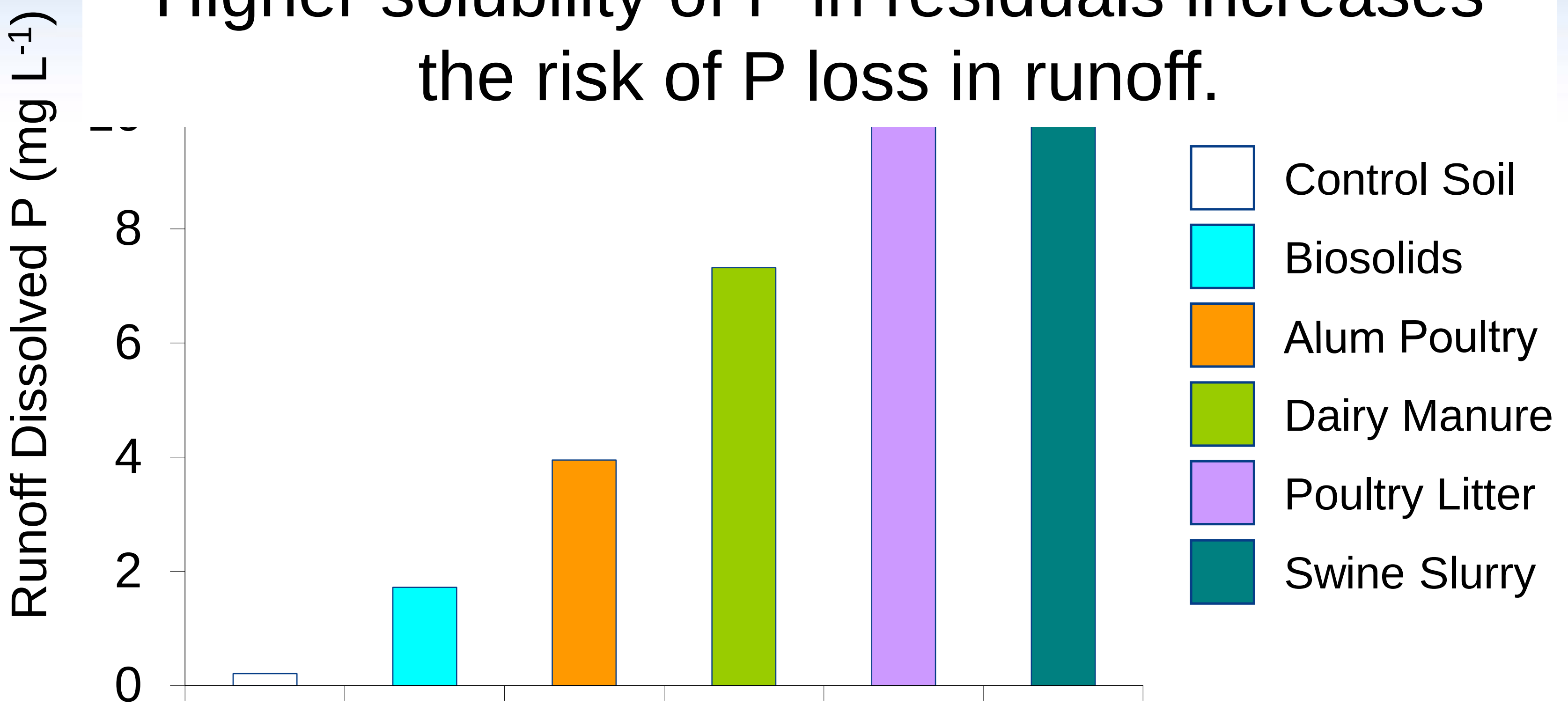


# BEHAVIOR OF P IN RESIDUALS-AMENDED SOILS

Kleinman et al. (2005)

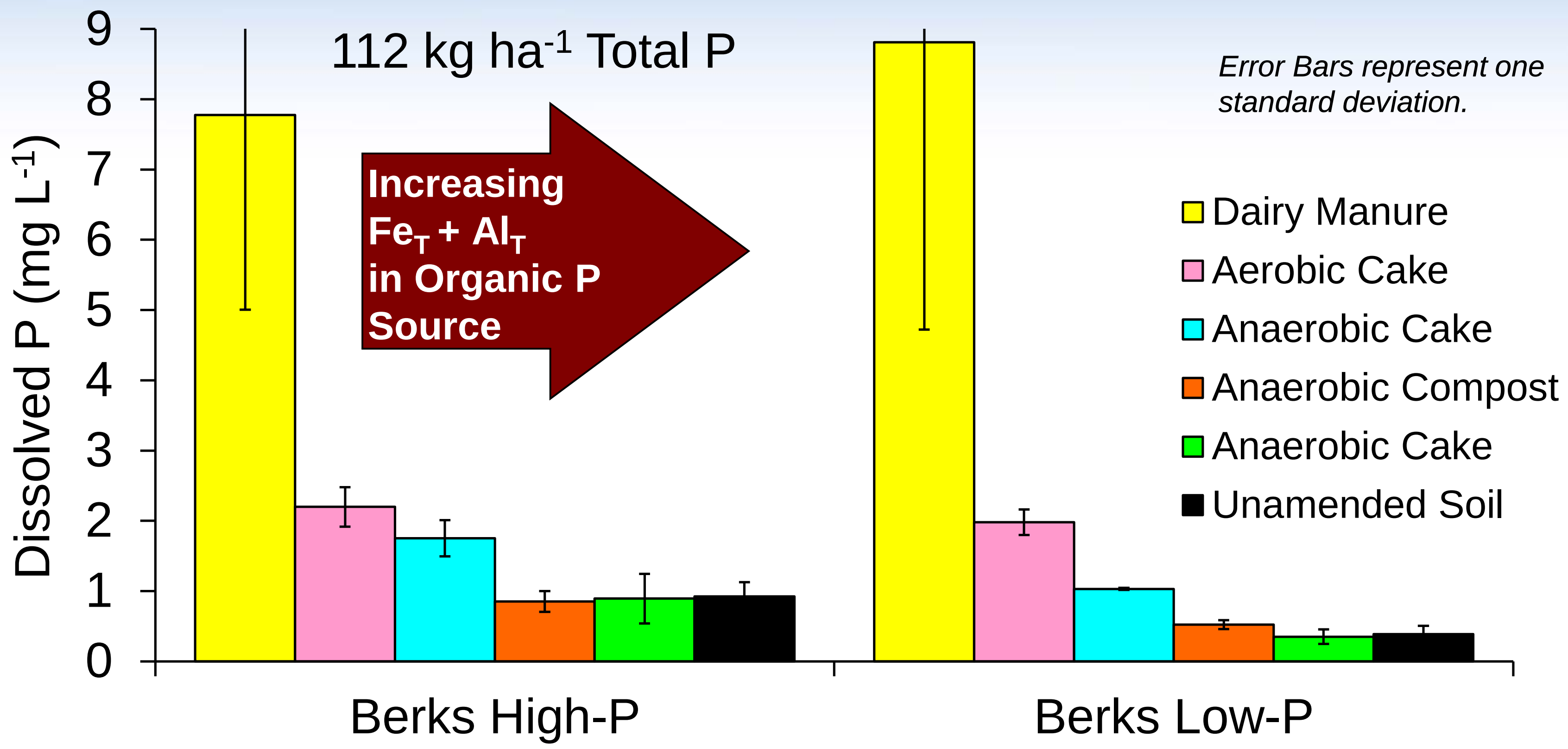
# Runoff Losses from Surface Applied Residuals

Higher solubility of P in residuals increases the risk of P loss in runoff.

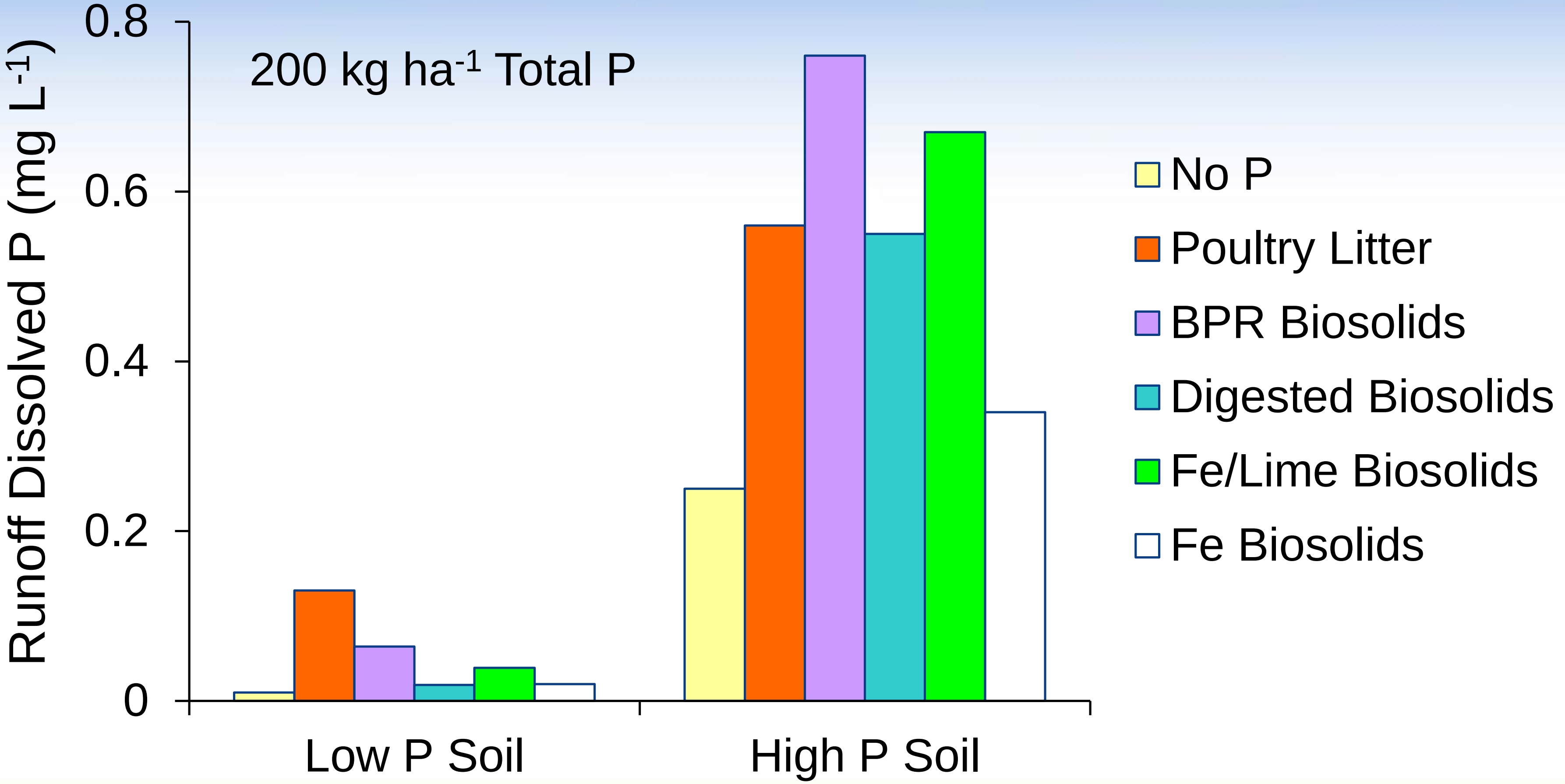


Brandt et al. (2003)

# Soil Properties Runoff P from Surface Applied Residuals



# P in Runoff Incorporated Residuals is Affected by Soil and Source



# Soil P Solubility Following Incorporation of Biosolids

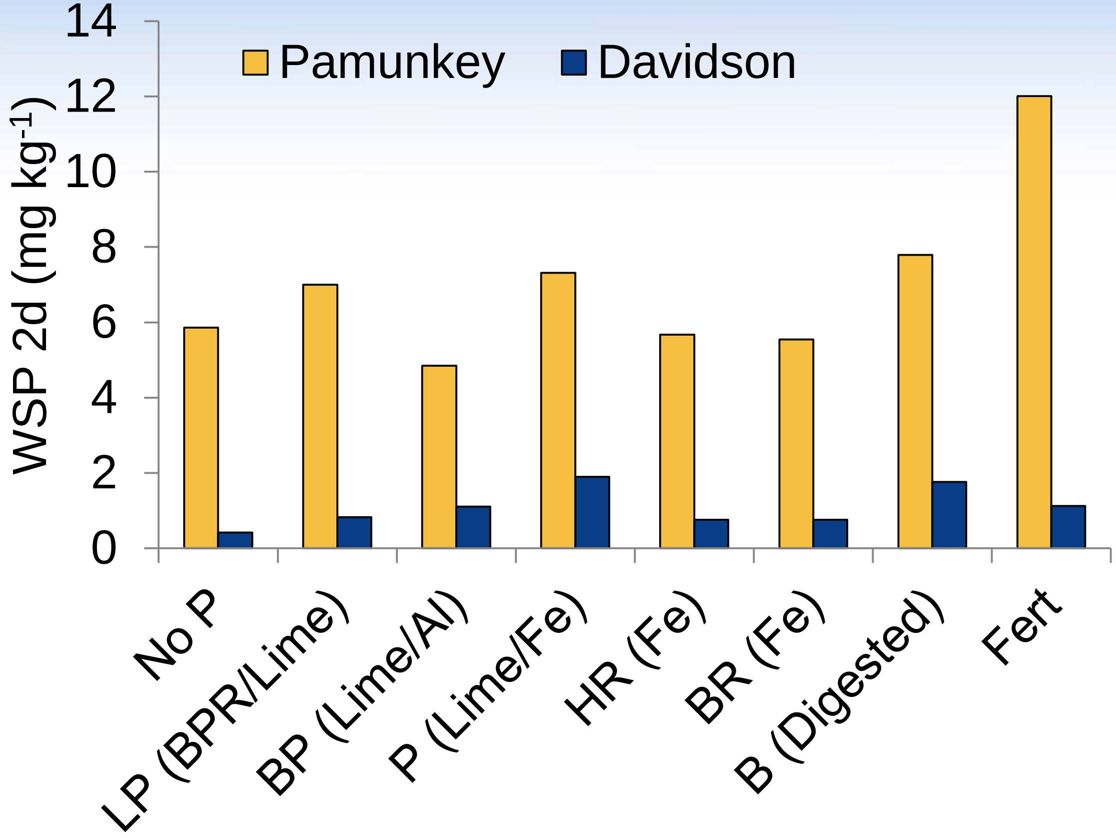
Davidson clay

- Soil Test P = 27 mg $kg^{-1}$ (Mehlich 3)
- P Saturation = 0.02

Pamunkey sand

- Soil Test P = 134 mg $kg^{-1}$
- P Saturation = 0.18

P Rate = 135 kg total P $ha^{-1}$



Shober and Sims (2007)

# Predicting Short-term Solubility from Incorporated Biosolids

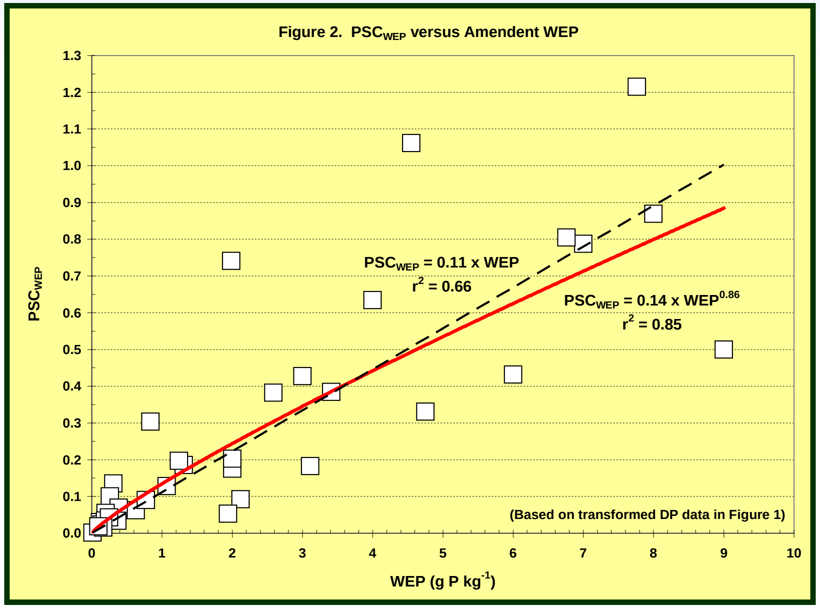
| Soil Property | P Source Property | $r^2$ ($P < 0.01$) | | |
|---|---|---|---|---|
| | | 2 d | 30 d | 180 d |
| DPS | None | 0.69 | 0.77 | 0.79 |
| M3-PSR | None | 0.65 | 0.74 | 0.74 |
| M3-P | None | 0.54 | 0.62 | 0.57 |
| None | WEP | 0.41 | 0.38 | 0.21 |
| None | WEP/TP ratio | 0.49 | 0.34 | 0.21 |
| DPS | WEP | 0.64 | 0.73 | 0.66 |
| M3-PSR | WEP | 0.59 | 0.68 | 0.59 |
| M3-PSR | WEP/TP ratio | 0.68 | 0.66 | 0.61 |

# Phosphorus Source Coefficients

## Regional Default Values

| Organic P Source | PSC |
|---|---|
| Inorganic P fertilizer | 1.0 |
| Swine slurry | 1.0 |
| Non-stabilized beef, dairy, poultry and other manures | 0.8 |
| Biological nutrient removal biosolids | 0.8 |
| Alum-treated poultry litters | 0.5 |
| Biosolids (except BNR) | 0.4 |

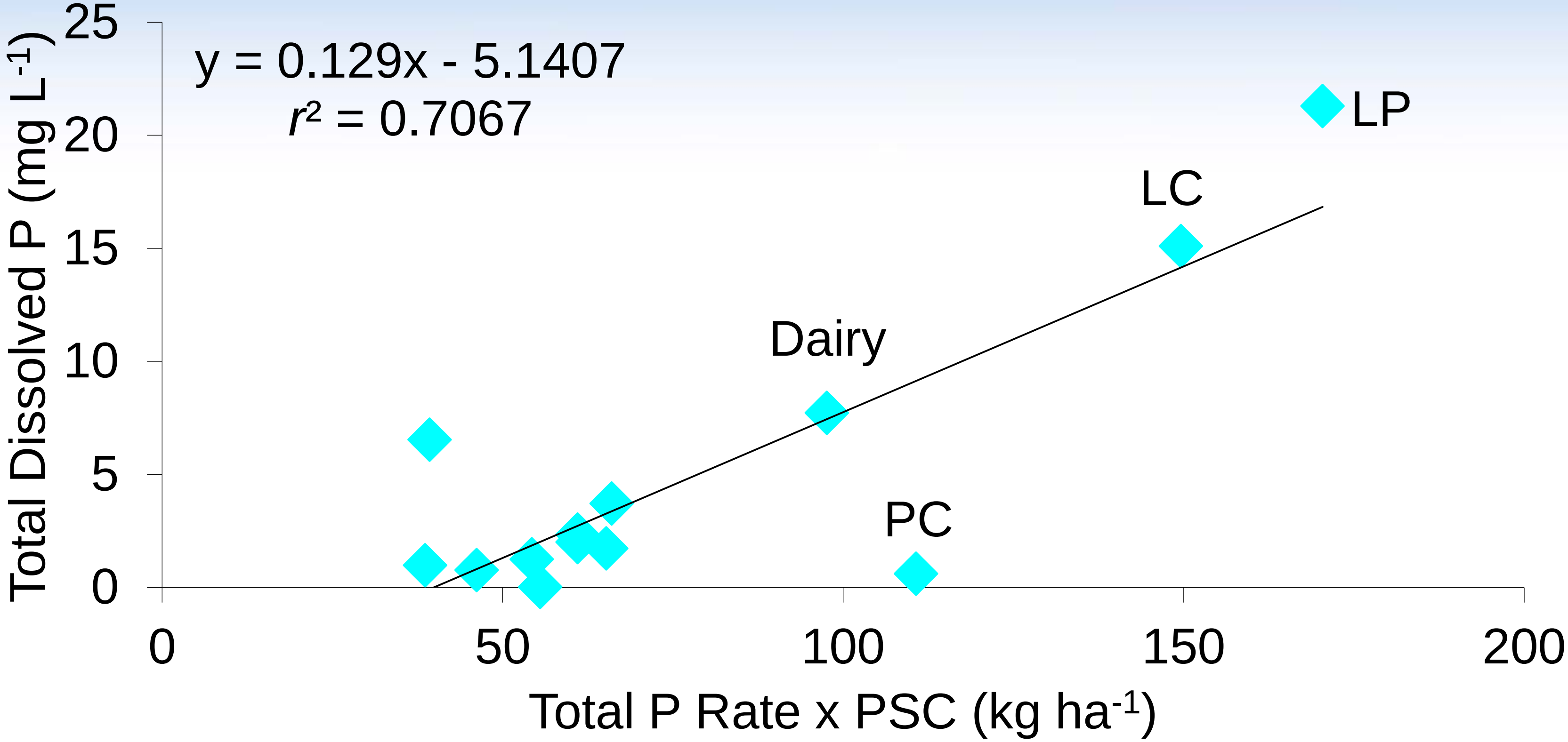
## Source Specific Values




**PSC = 1.17 x WEP (%)**

Elliott et al. (2005)

# Surface Applications and P Source Coefficients

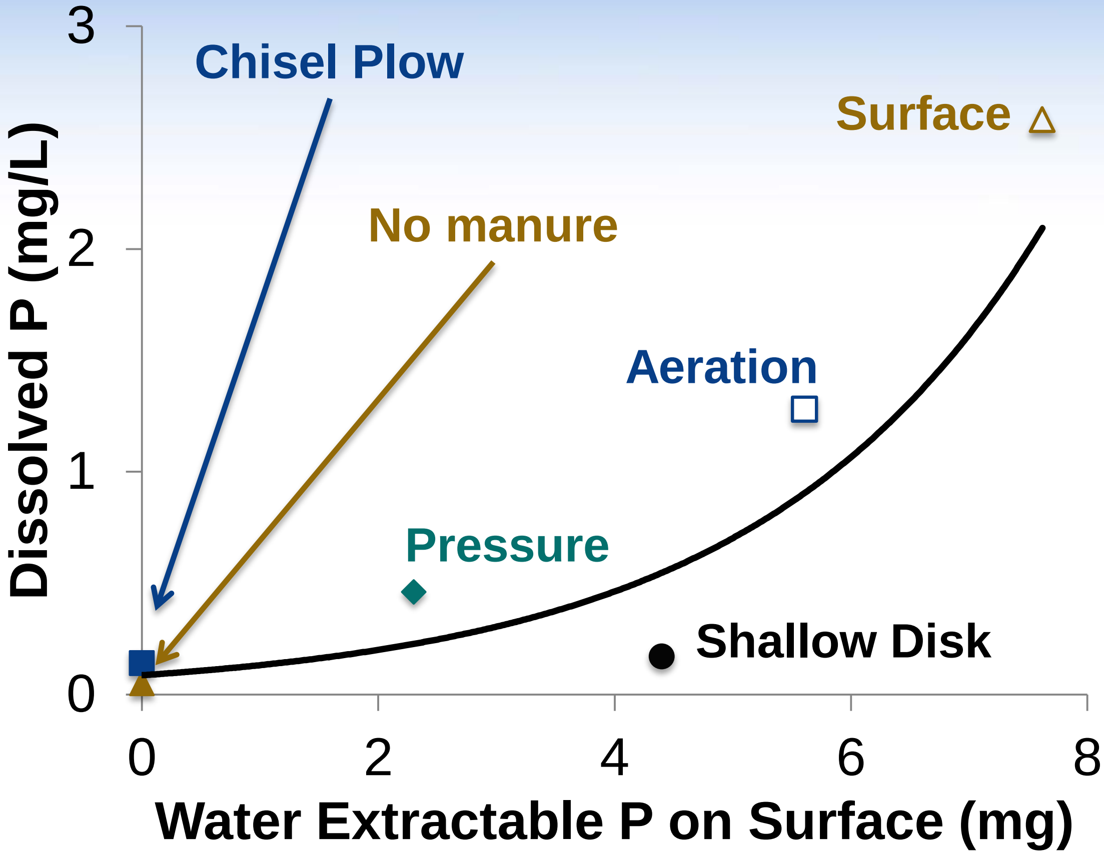


# Subsurface Application – Benefits of Incorporation with Low Disturbance

Heavy Cover Crop

Permanent Pasture

# Manure Application Method Affects Phosphorus Loss

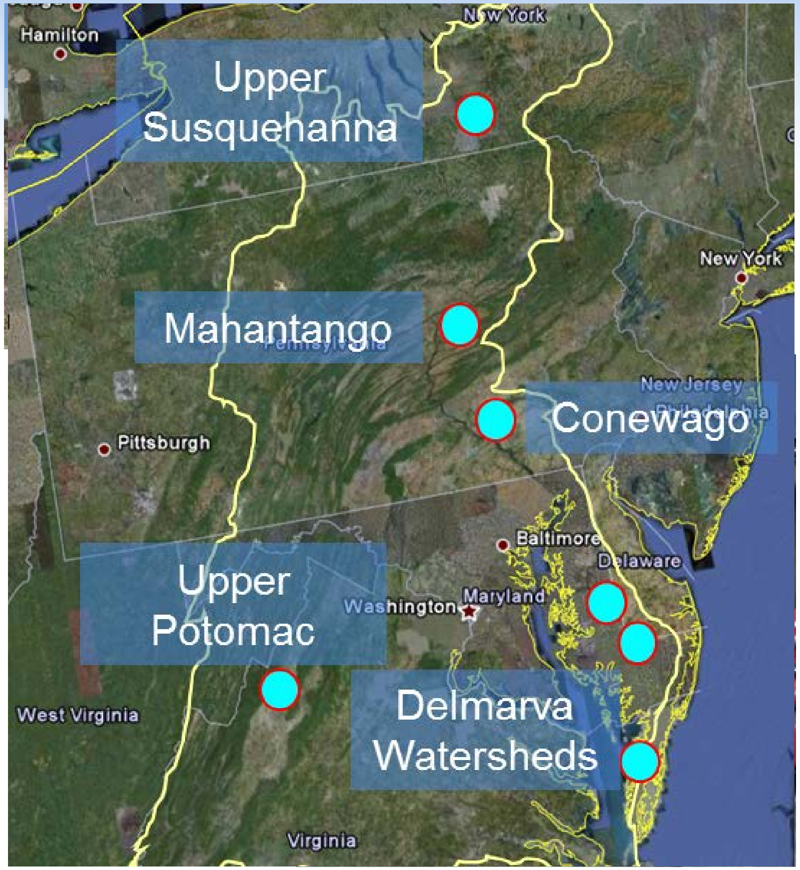


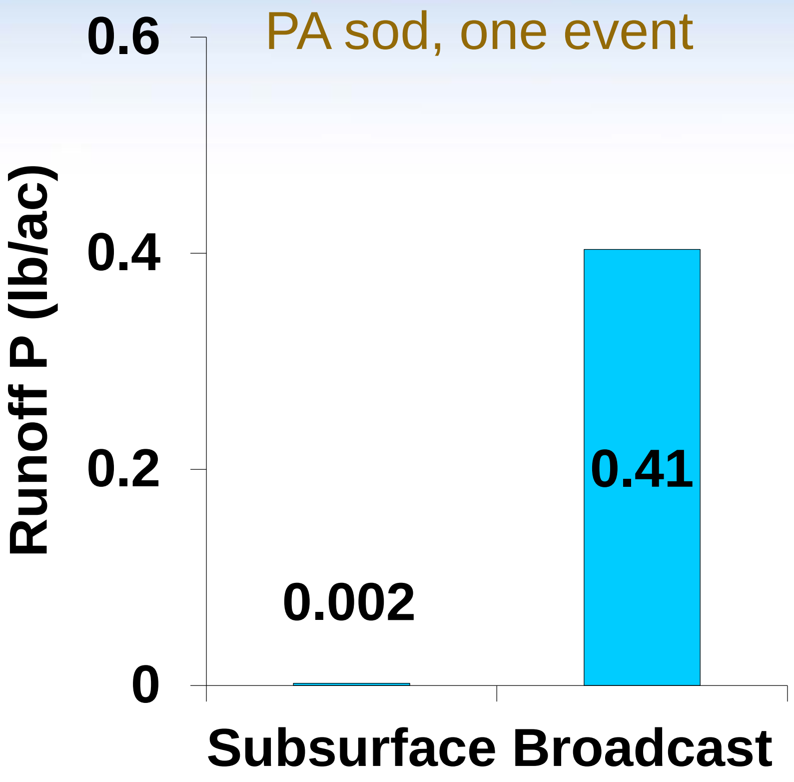


More P at surface = More P in runoff

P. Kleinman, personal communication

# Subsurface Application of Solid Manures in No-Till/Pasture



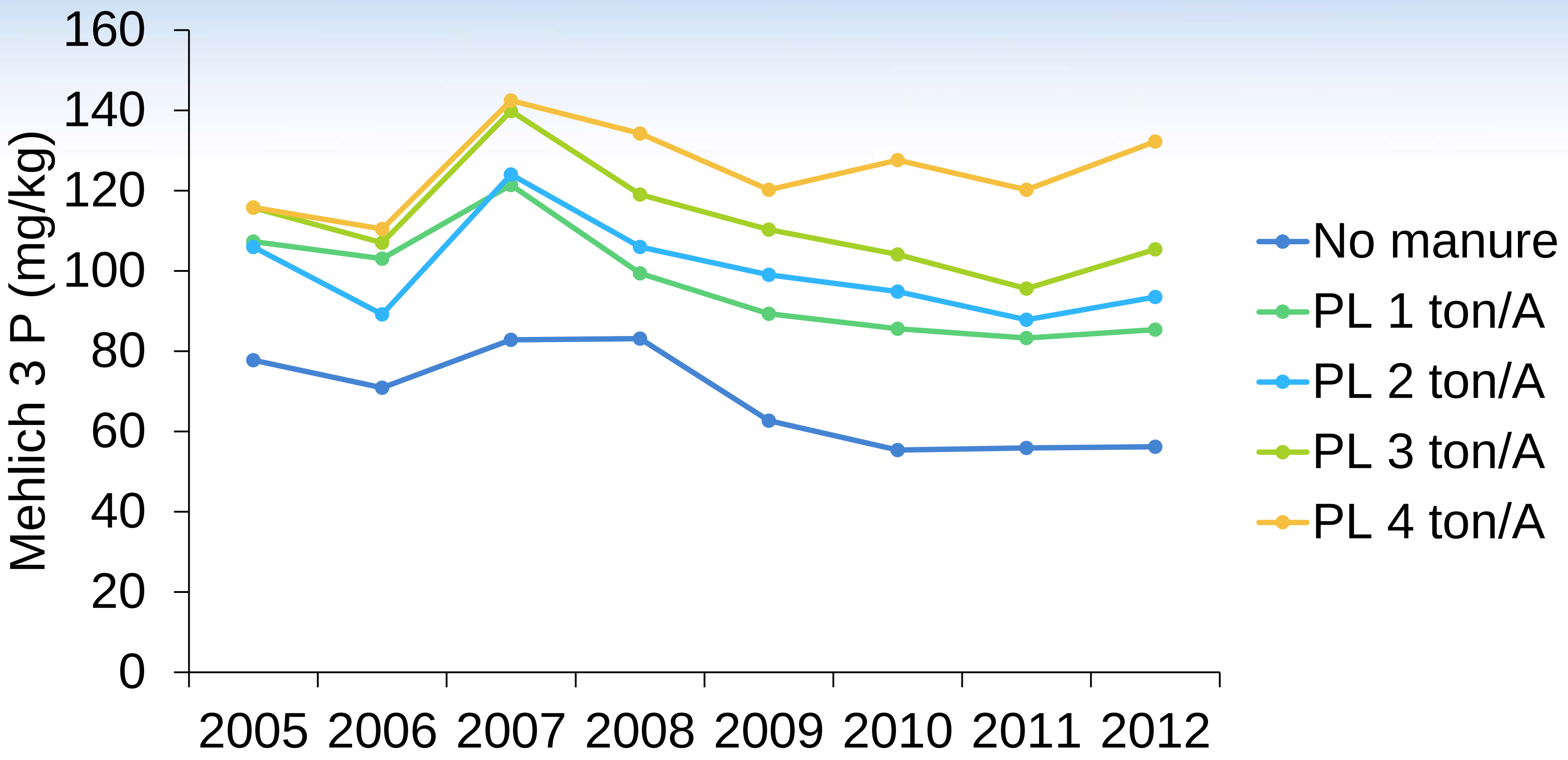
Managing Phosphorus in Organic Residuals Applied to Soils

# LONG-TERM FATE OF P IN RESIDUAL-AMENDED SOILS

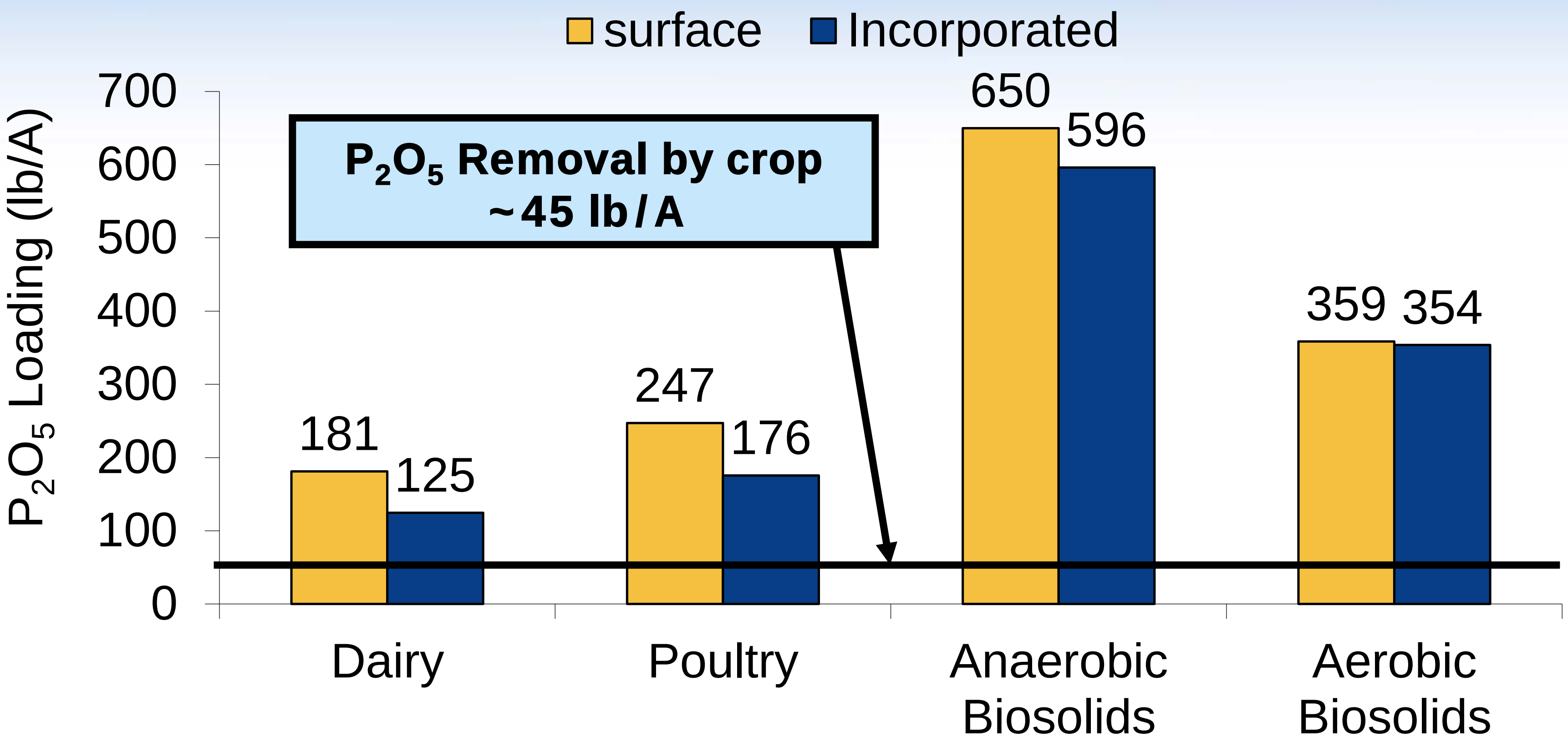
# Nutrient Content in Residuals

| Residual Type | Total N | Total $P_2O_5$ | $N:P_2O_5$ ratio |
|---|---|---|---|
| Solids | —— lbs/ton —— | | |
| Beef cattle | 12 | 5 | 2.40 |
| Biosolids | 95 | 104 | 0.91 |
| Broiler litter | 57 | 45 | 1.27 |
| Dairy | 10 | 4 | 2.50 |
| Liquids | —— lbs/1,000 gal —— | | |
| Dairy | 28 | 13 | 2.15 |
| Swine | 27 | 19 | 1.42 |

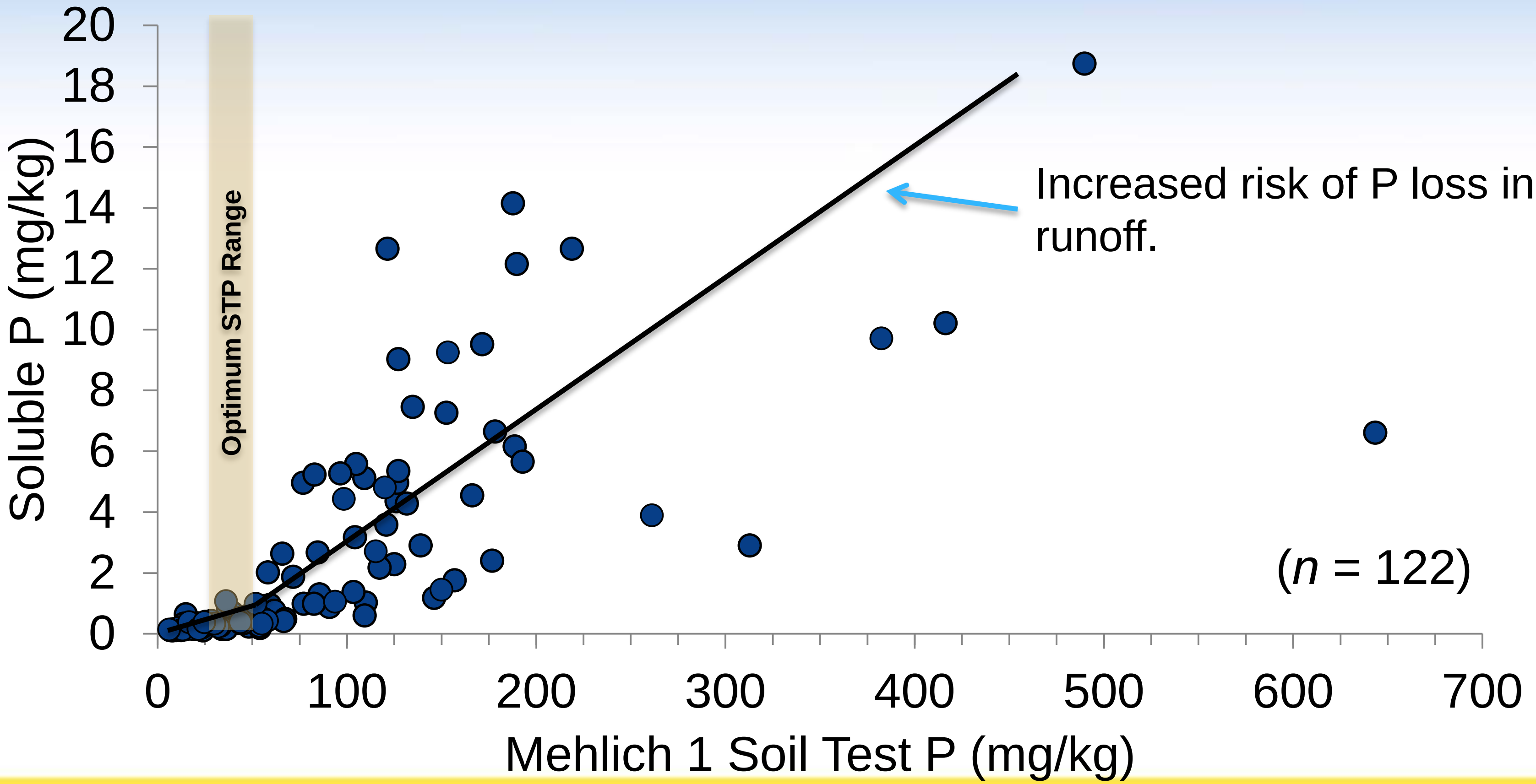
# Application of Manure at Crop P Removal



# $P_2O_5$ Loadings for Residual Application at N-based Rates

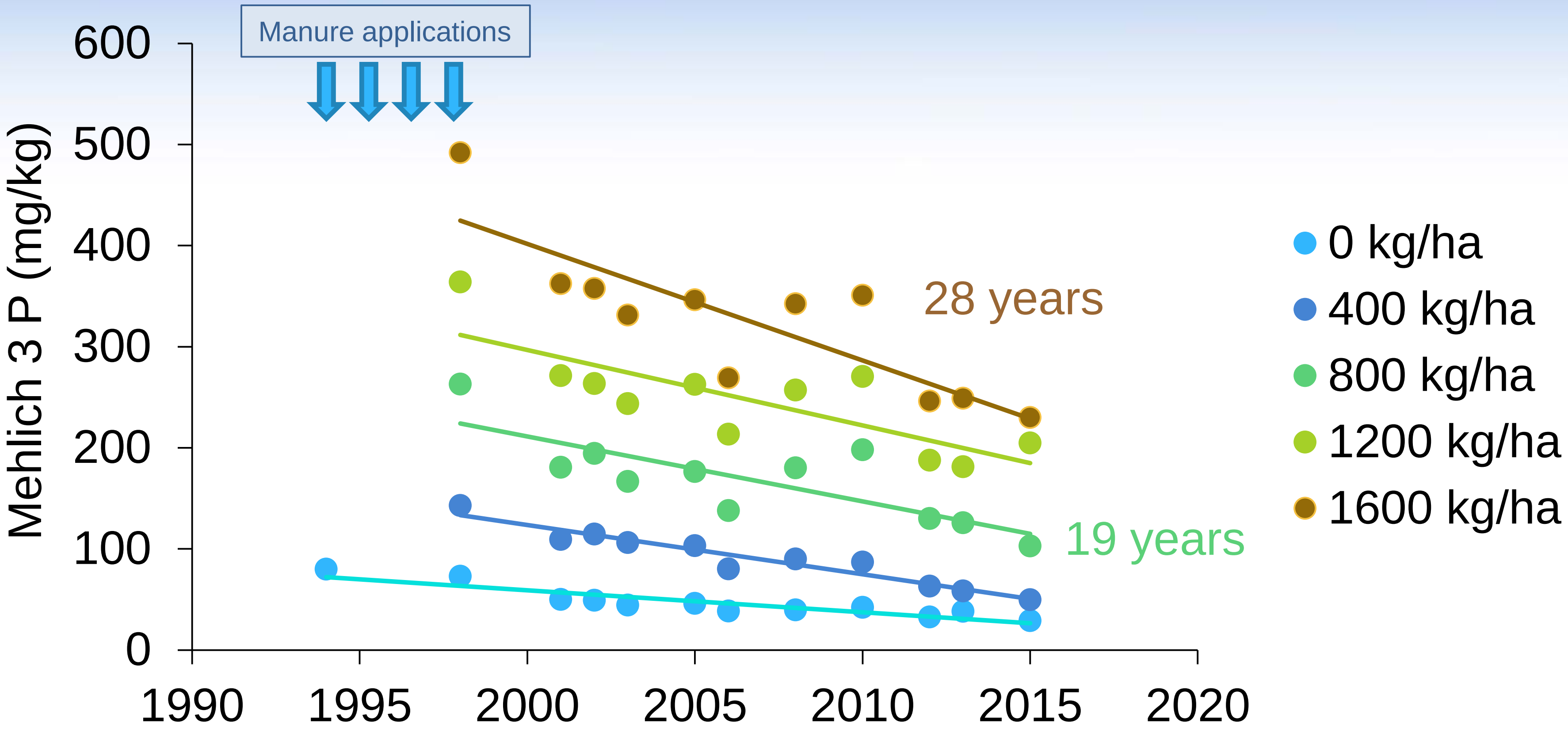


# Relationship Between Soil Test P and Soluble P in Soils

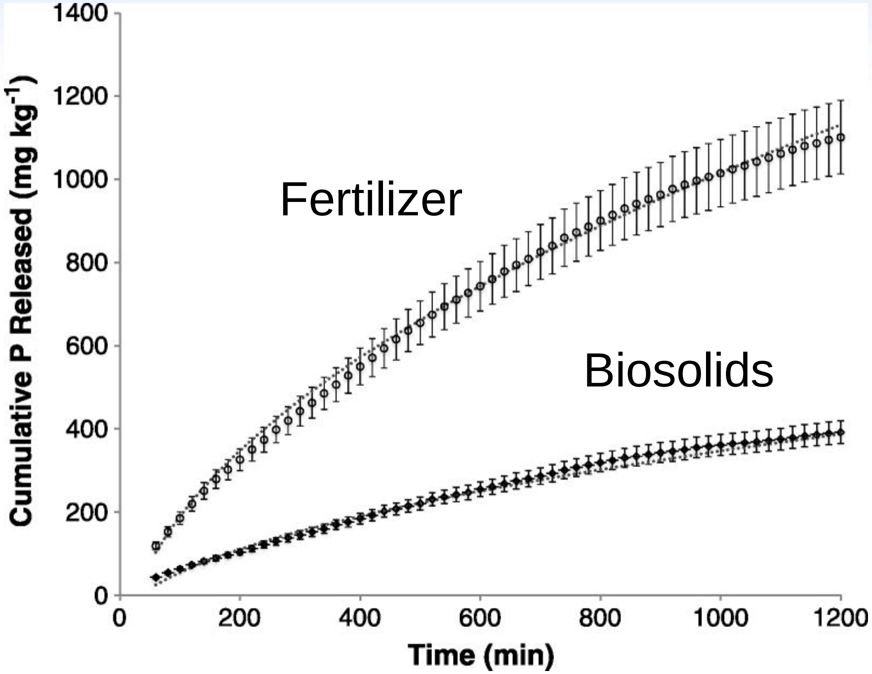


Coale et al. (2013)

# Phosphorus Drawdown Following Manure Application

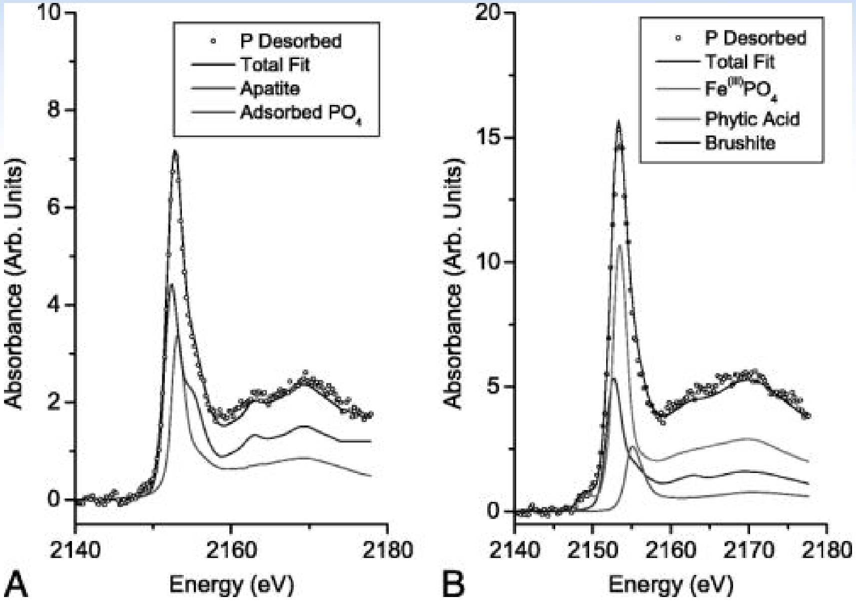


# Dissolution of P from Soils Receiving Biosoilds or Fertilizer




- Anaerobically digested biosolids (Chicago) application for 32 yr (67.2 Mg ha$^{-1}$ yr$^{-1}$)
- Continuous flow desorption with 0.1 *M* $NaNO_3$
- 4 × slower dissolution of P from biosolids-amended soils

# Dissolution of P from Soils Receiving Biosoilds or Fertilizer




XANES analysis on soils after dissolution experiment (Peak et al. 2012)

- Fertilizer: apatite (Ca-P) and adsorbed $PO_4$
- Biosolids: brushite (Ca-P), strengite (Fe-P), organic P
- Slow dissolution of Ca-P and Fe-P minerals

# What is the Fate of Biosolids P in Acid Soils?

- Lime Biosolids: Slow solubilzation of crystalline Ca-P
- Fe Biosolids: Ferrihydrite-P should remain stable; Excess ferrihydrite may sorb native soil P
- Fe & Lime: pH change = Ca-P solubilization; Ferrihydrite may act as P sorbent
- BPR and Digested biosolids: Ca-P solubilization; Al-P fairly stable

# Summary

- Advanced techniques have improved our understanding of P speciation in residuals
- Treatment processes have large impact on P solubility and speciation
- Lower P solubility related to Fe- and lime-stabilization
- P losses controlled by residuals properties (surface applied); residuals and soil properties (incorporated)

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# Acknowledgements


- Research was conducted (in part) at the National Synchrotron Light Source (NSLS), Brookhaven National Laboratory, which is supported by the U.S. Department of Energy, Division of Materials Science and Division of Chemical Services
- Funding provided by Metropolitan Washington Council of Governments, Washington, DC, USA