Metropolitan Water Reclamation District of Greater Chicago

Protecting Our Water Environment

Plant Availability and Environmental Significance of Phosphorus in Land-Applied District Biosolids

Guanglong Tian

Kuldip Kumar

Albert Cox

Acknowledgements

- Section 123 Technicians and Chemist
  - Field and greenhouse work, lab analyses etc.
- Rosalie Swango and other M&O staff at Fulton County
  - Field and greenhouse work, lab analyses etc.
- Analytical Labs Division
  - Analyses

But Phosphorus is a Good Thing

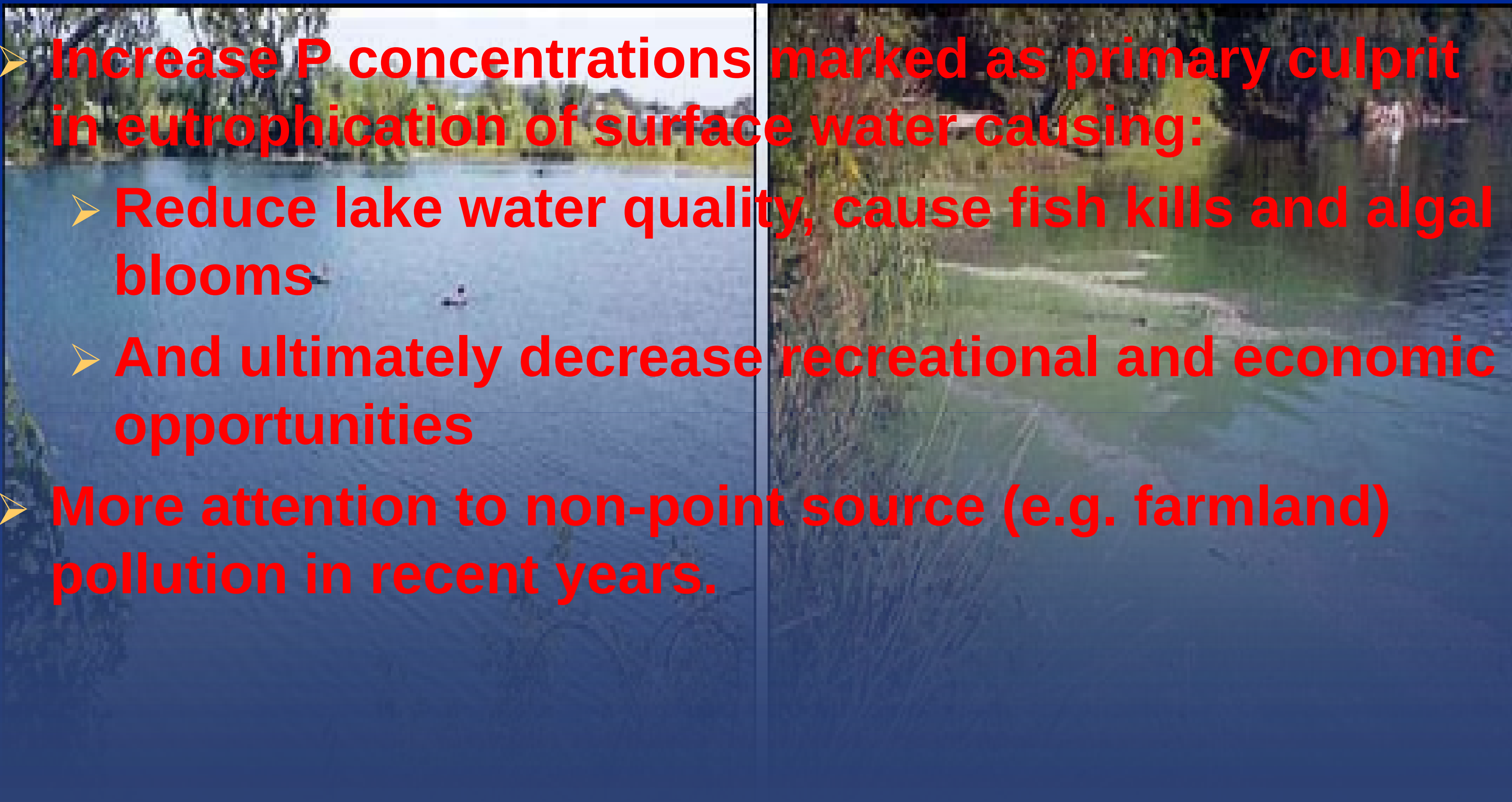
Humans and Animals

- Essential ingredient of all cell protoplasm, nervous tissue, and bones
- Part of DNA material
- Primary factor in energy distribution (ATP)

Plants

- An essential plant macro-nutrient
- Formation of sugars and starches and conversion of solar energy into chemical energy
- Stimulation of early growth and root formation, and promotes plant hardiness and seed production

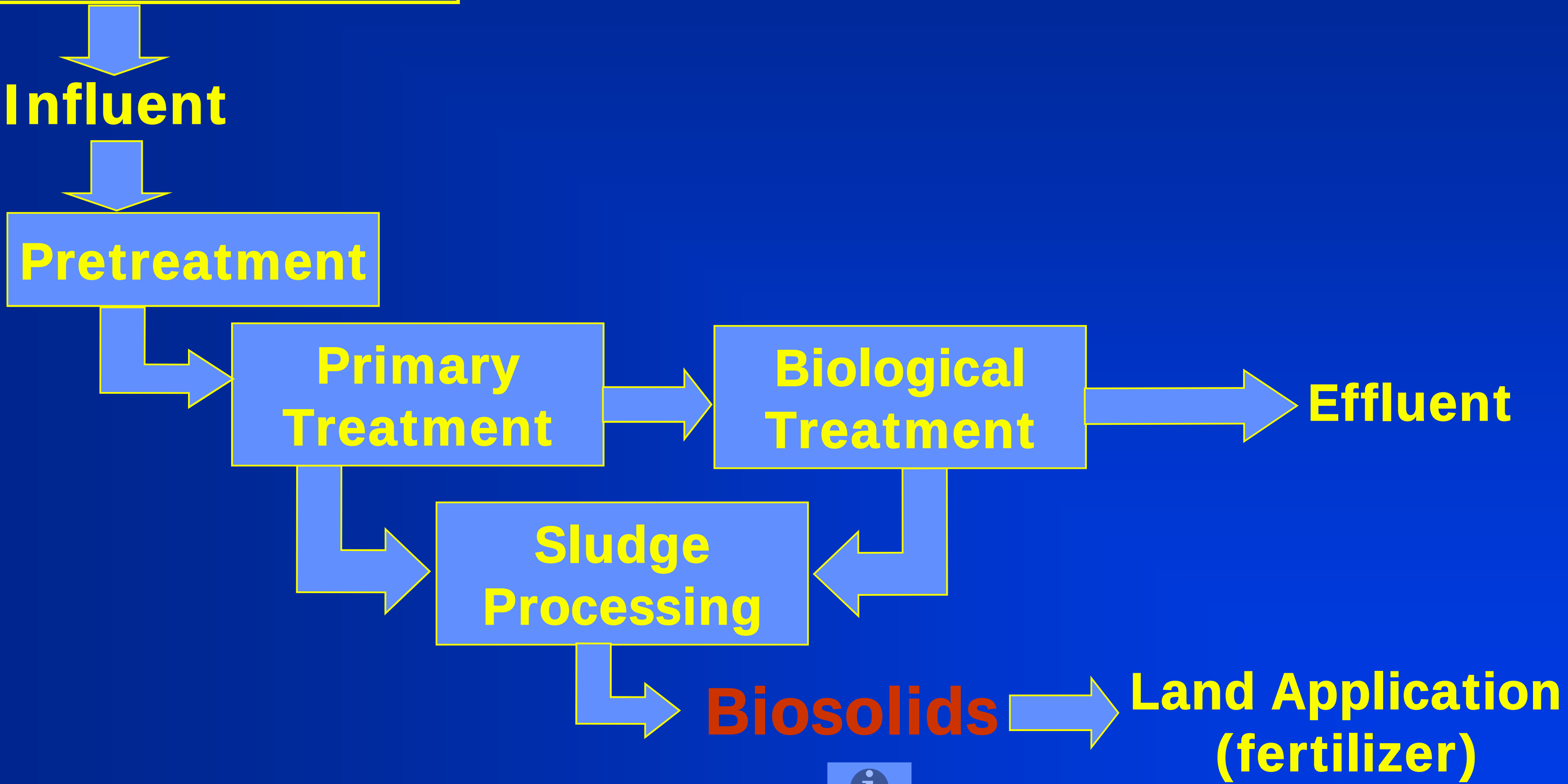
So What's the Concern?



- Increase P concentrations marked as primary culprit in eutrophication of surface water causing:
  - Reduce lake water quality, cause fish kills and algal blooms
  - And ultimately decrease recreational and economic opportunities
- More attention to non-point source (e.g. farmland) pollution in recent years.

Phosphorus in Wastewater Treatment Process

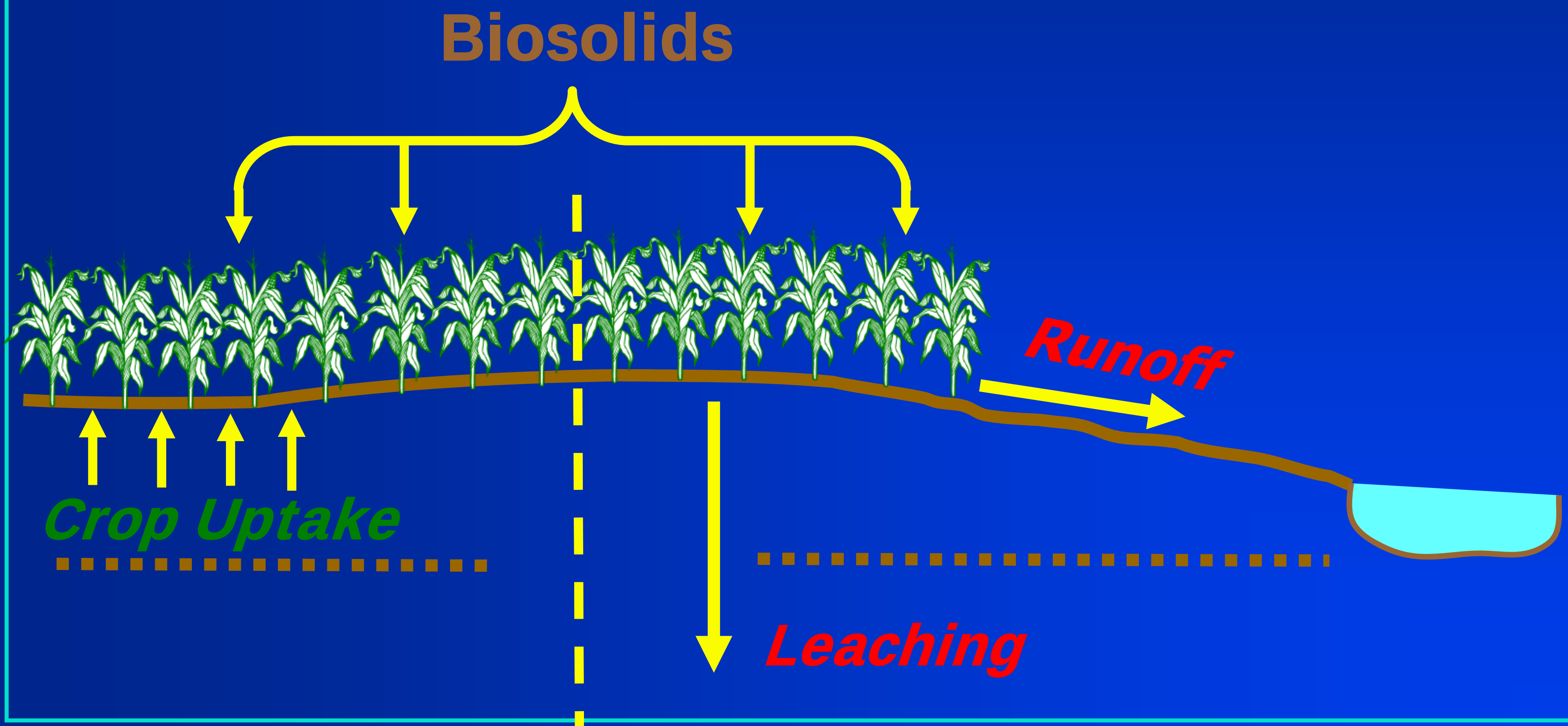
- Fertilizer runoff
- Detergents
- Excreta



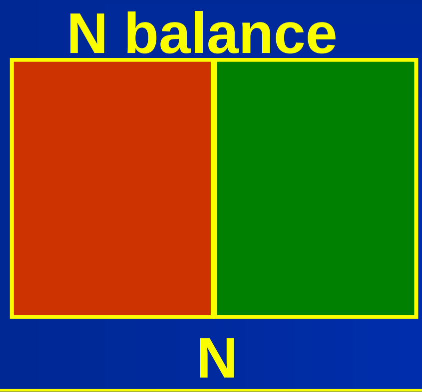
Over 60 % of District's 180 dry tons/yr

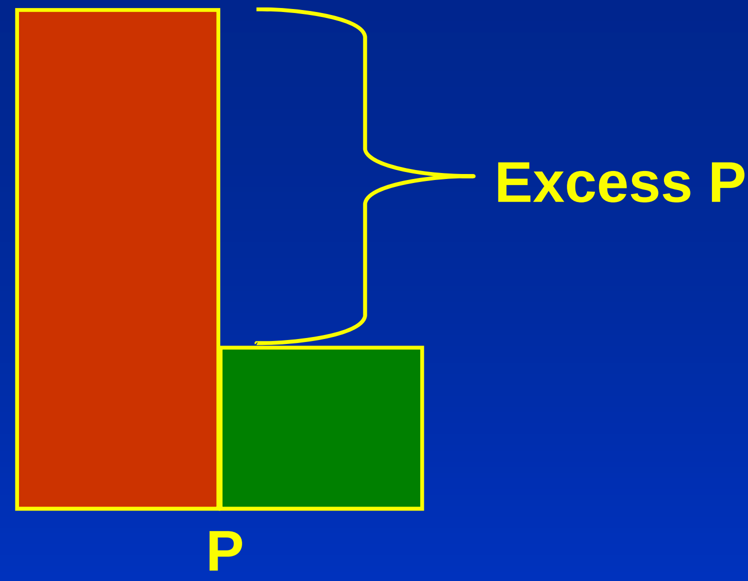
AGRONOMIC IMPACTS

ENVIRONMENTAL IMPACTS

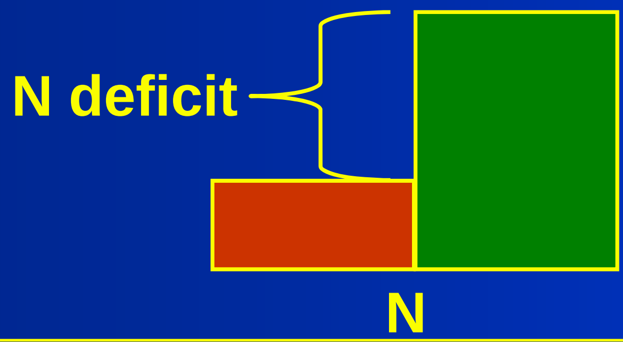


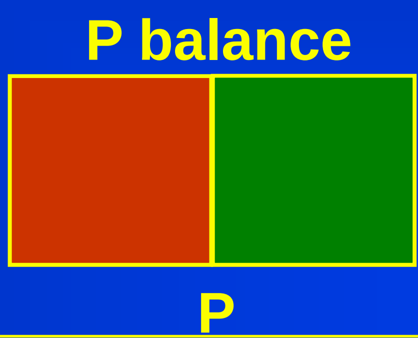
N-based Application Rates





P-based Application Rates

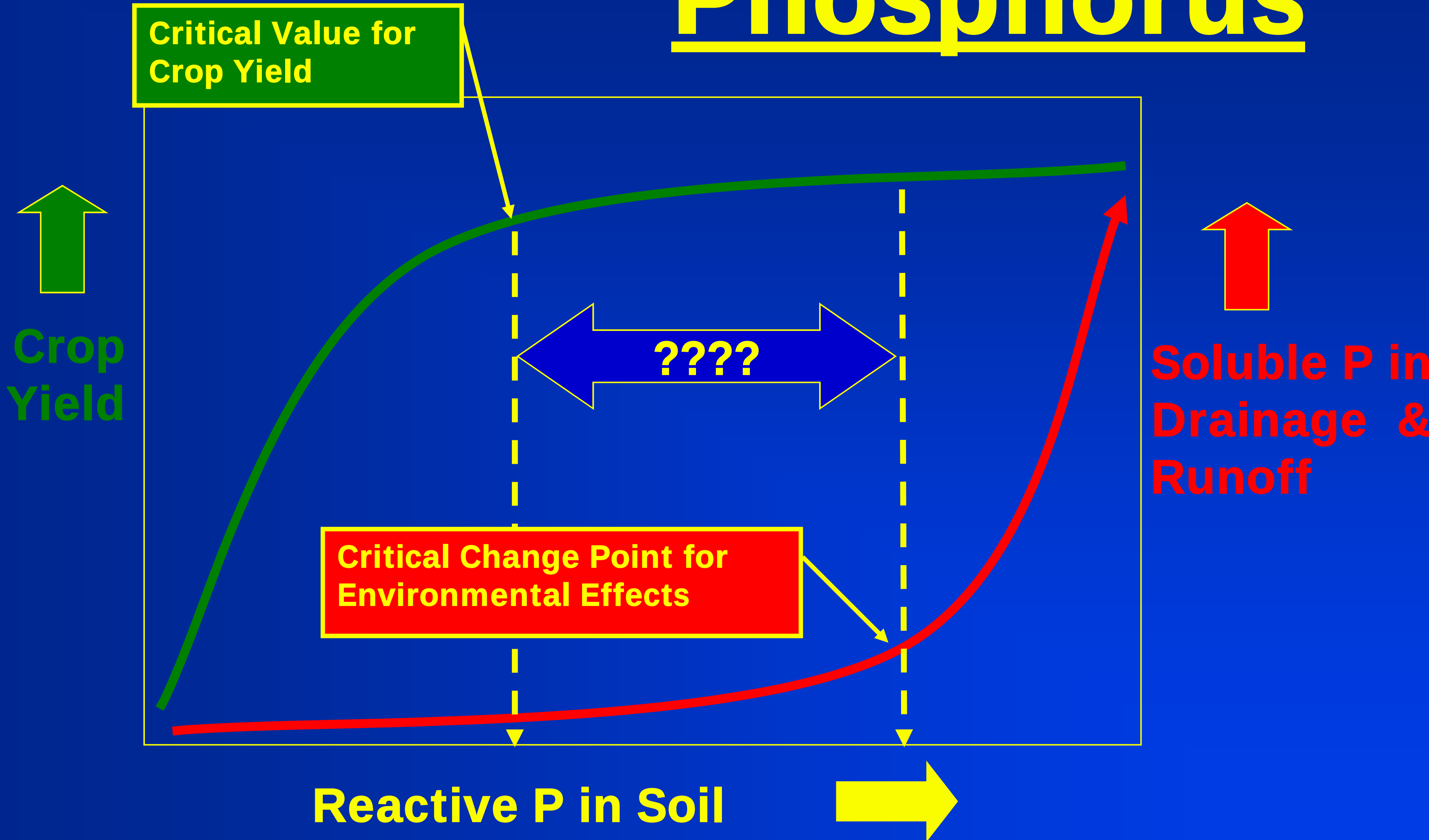




Biosolids Content

Crop Requirement

Phosphorus


Critical Value for
Crop Yield
Crop
Yield
????
Soluble P in
Drainage &
Runoff
Critical Change Point for
Environmental Effects
Reactive P in Soil

Efforts to Minimize Agricultural P Impacts

P-Based Nutrient Management

- USDA-NRCS 590 Standard: P-based plans based on site characteristics and vulnerability of water bodies
  - Options
- USEPA – Confined Animal Feeding Operation (CAFO): Nutrient Management Plan

According to IEPA: CAFO rule may form basis of P-based rate biosolids rule in Illinois

  - No application where soil test P >300 lbs/ac (150 mg/kg)
  - Only amt. P to meet crop needs (single or multiple seasons)
  - Buffer: 100 ft from surface water

How Might P-based Application Affect District Biosolids Farmland Program?

- Need more land for application
  - Longer distance, higher costs
  - Scenario: To utilize 100,000 dry tons/yr
    At current N-based rate of ~10 tons/ac, we need 10,000 acres
    At P-based (~2.5 dry tons/ac), we'll need ~40,000 acres
- Farmers will need to apply supplemental N fertilizer
- Difficult and probably impractical to accurately apply <5 dry tons/ac

Soil Test P in 100 Fields in District Biosolids Farmland Application Program 2009 -2010

Soil Test P Range (lbs/ac)	No. of Fields	Rating
<40	20	Low
40 - 50	8	Low
60 - 80	5	High
>80	60	Very High
>300	7	Prohibited

Agronomic

Average for fields at <300 lbs/ac = 114 lbs/ac

Typical Characteristics of MWRD Biosolids Controlling Fate of P

Total Al (%)	2.0 – 3.0
Total Fe (%)	2.5 – 4.5
Water Soluble P (1:25 solid:water), mg/kg	60 – 120
Total P (%)	1.8 – 2.5
(lbs P/ton)	36 - 50

IEPA's Top Questions

District & IEPA Collaborative P Research

1. Could a P coefficient be developed which would predict what portion of the total P contained in biosolids would be available for plant uptake?
2. Is there a residual availability of P over time similar to the residual contribution of N over 5-year of application? If Yes? How much?
3. How much of a reduction in P runoff would occur if biosolids were incorporated rather than surface applied?
4. What is the appropriate buffer zone to limit P runoff? The Agency is tentatively proposing a 100-ft buffer from surface water. Is this enough, too much or too little?

Biosolids P Studies

- **Bioavailability: Greenhouse Study – Albert Cox**
  - A coefficient can be used to account for lower bioavailability of biosolids P compared to fertilizer P, with respect to soil test P and plant uptake
  - Residual biosolids P in soil is released slowly over time
- **Bioavailability: Field Studies – Guanglong Tian**
  - Confirm findings of greenhouse study
  - How data can be used to develop P-based guidelines
- **P Runoff Biosolids Studies – Kuldip Kumar**
  - Runoff potential of biosolids P
  - Length vegetative reasonable to protect surface waters

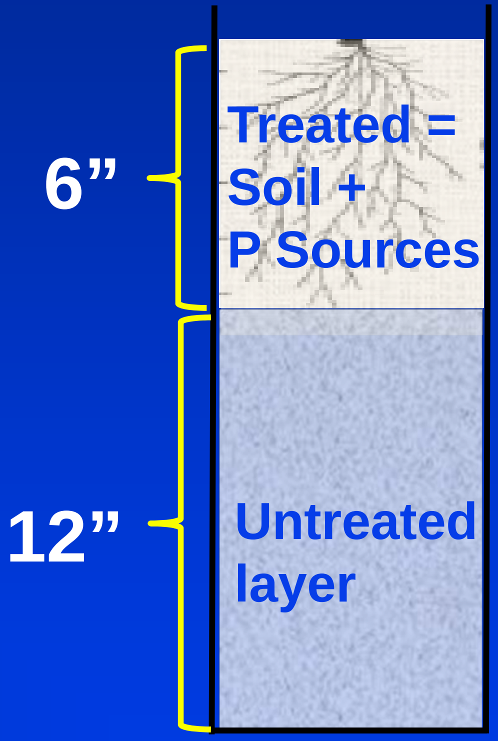
Imminent P-based Biosolids Land Application Rule

Is the District’s Farmland Application Program at Risk?

Bioavailability of Biosolids P
Greenhouse Study

Greenhouse Study: Methods

- **Soil:** P-deficient sandy soil (STP = 2.5 mg P/kg (5 lb/ac)
- **3 P sources**
  1. TSP (chemical fertilizer)
  2. Class A Air-dried biosolids
  3. Class B Centrifuge cake biosolids
- **6 targeted P rates:** 0 – 300 mg P/kg soil
- **4 Replicates**
- **Crop:** Alternating wheat & perennial rye
  - Clip foliage every 30, then regrow or reseed
  - Total of 18 crops



Relief Workers harvesting wheat Foliage

So what you doing
next summer, 2011?

I don't know!!
Not at the District!

Greenhouse Study: Methods

Soil Analyses (after every two crops)

- Soil Test P – Bray 1 method
- Water soluble P (WSP)
- Total P

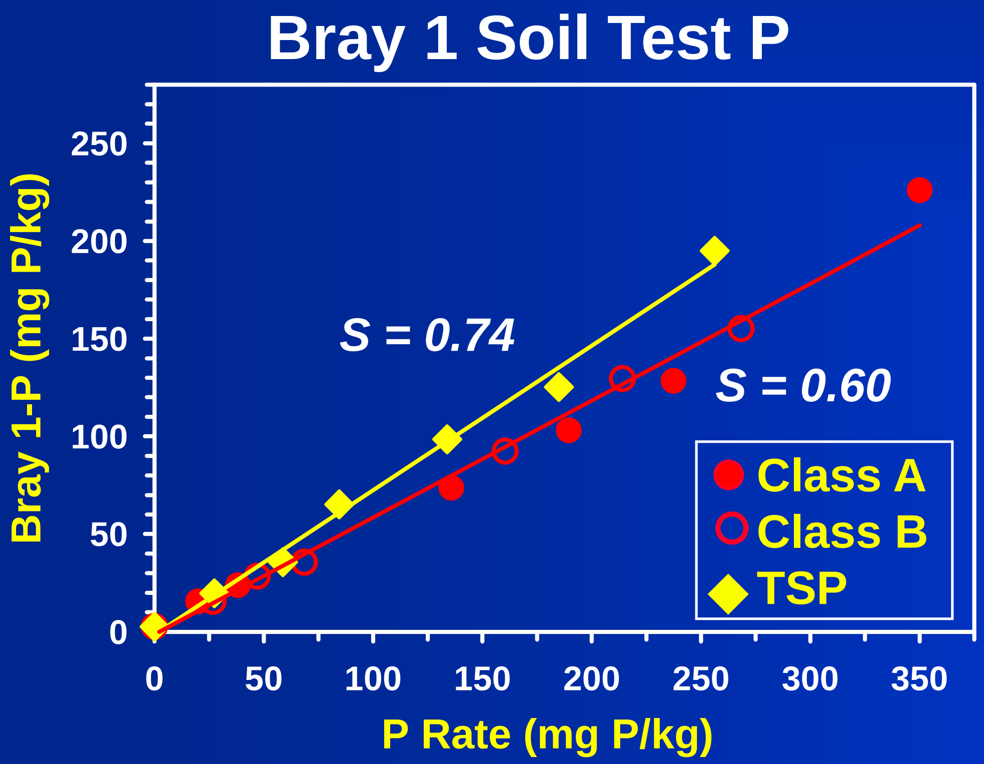
Plant Analyses

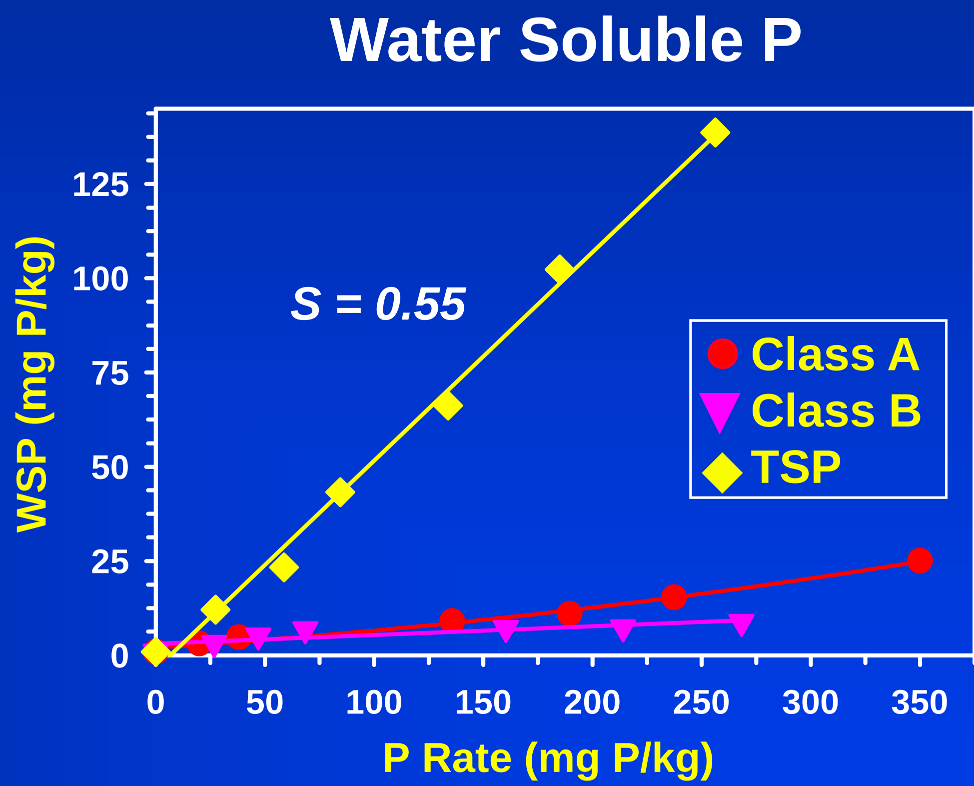
- Weigh foliage to determine dry matter (DM) yield
- Determine P conc. in tissue

Calculations

- P uptake = DM x P conc.
- Immediate availability = cum P uptake in first 3 crops
- Total availability = Cum P uptake in all 18 crops

How Did P Sources Change STP and WSP?



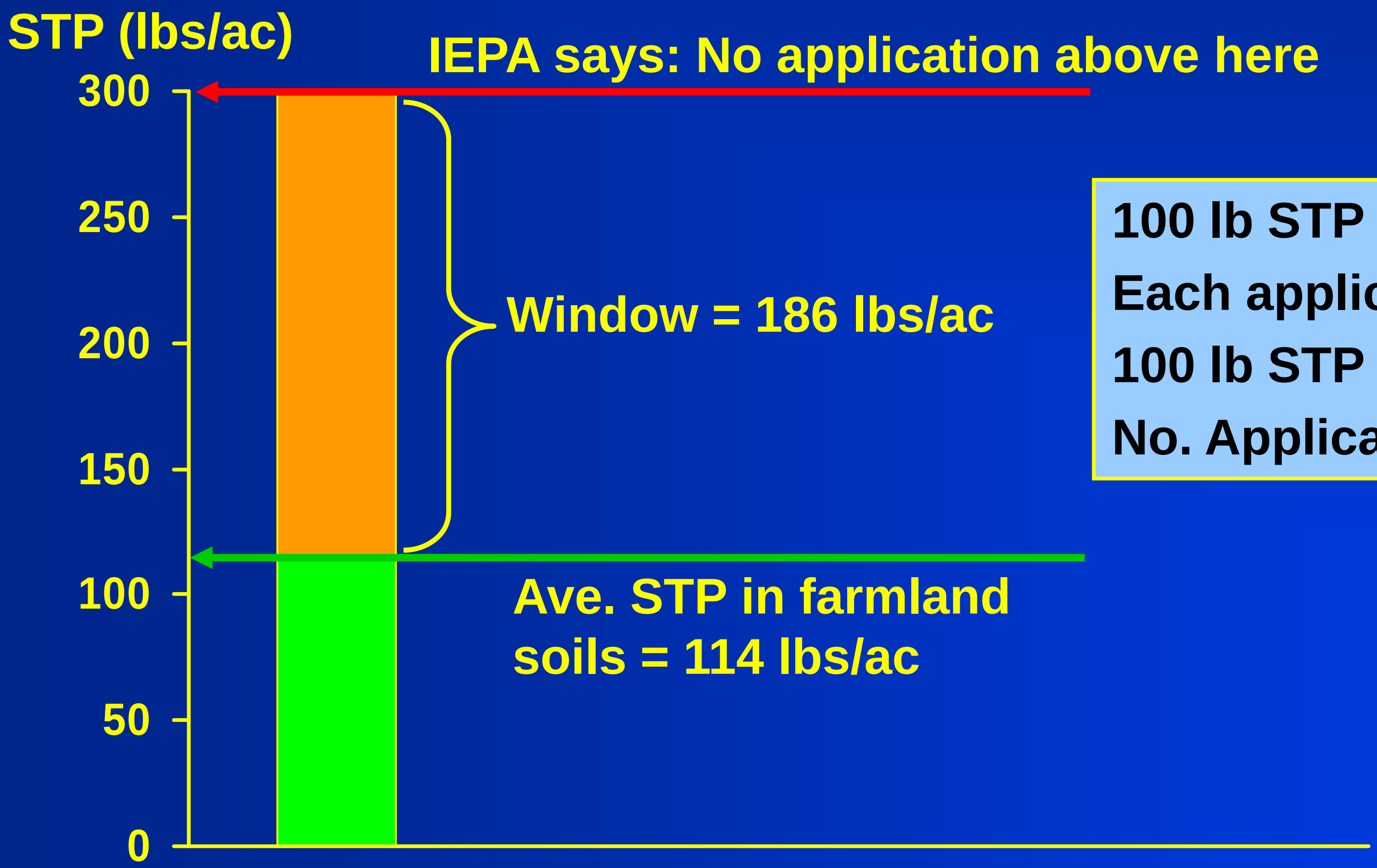


How Much P is Needed to Increase Bray 1 Soil Test P by 1 Pound?

	Immokalee Sand	Watseka Sand	Drummer clay loam	Fulton Co. clay loam
Initial STP (mg P/kg)	2.5	132	43	18
P Source	----- pounds P to raise STP by 1 pound -----			
TSP	1.3	1.2	1.6	3.7
Biosolids	1.7	3.6	7.9	7.2

Data from 2002 lab study

How Many More Applications before IEPA Limit?



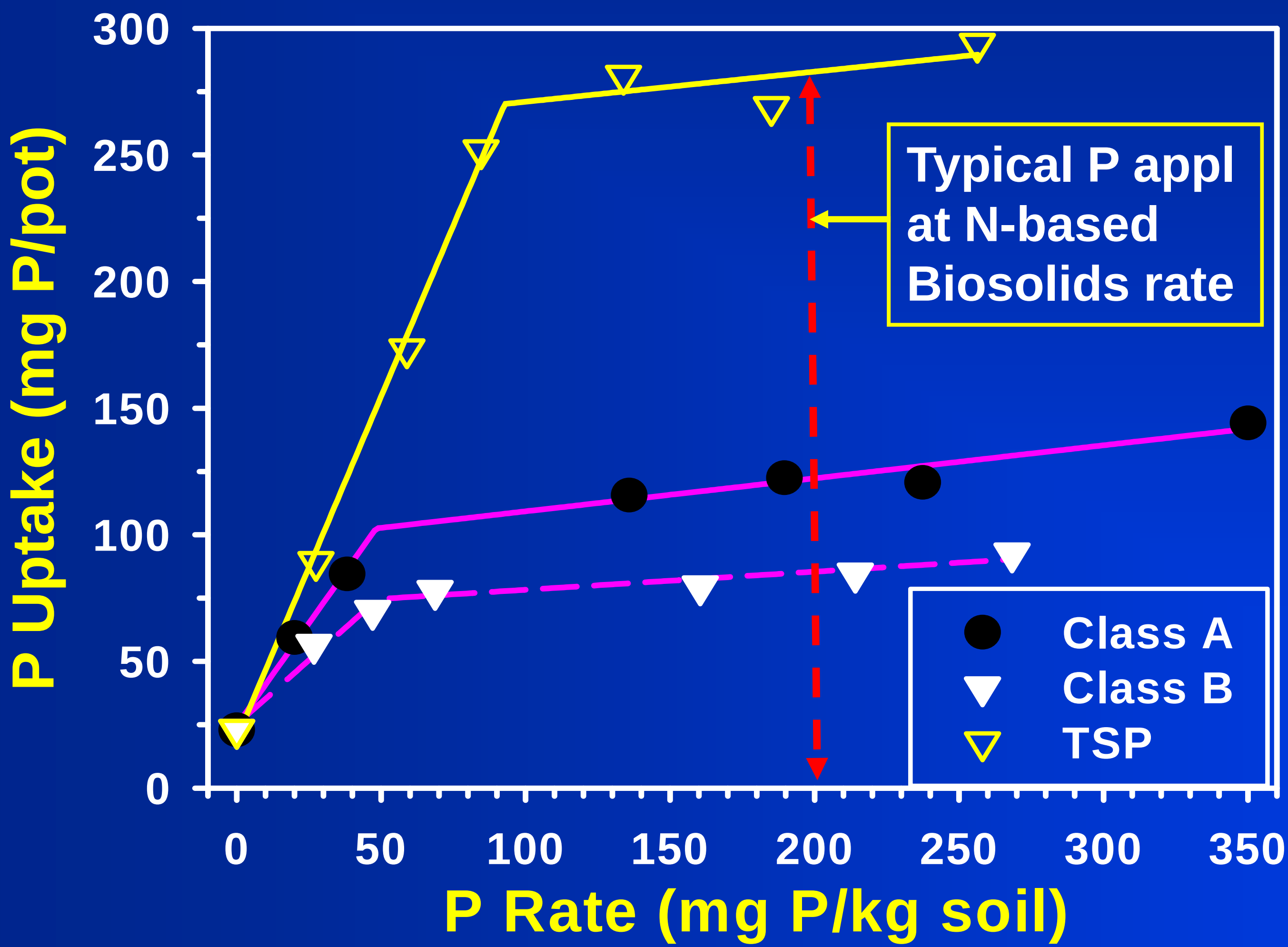
100 lb STP ~ 800 lb Biosolids P

Each application ~ 400 lbs P

100 lb STP ~ 2 applications

No. Applications ~ 4

Cumulative P Uptake in Three Consecutive Foliage Clipping: Immediate Plant Availability



Relative effectiveness

TSP = 100%

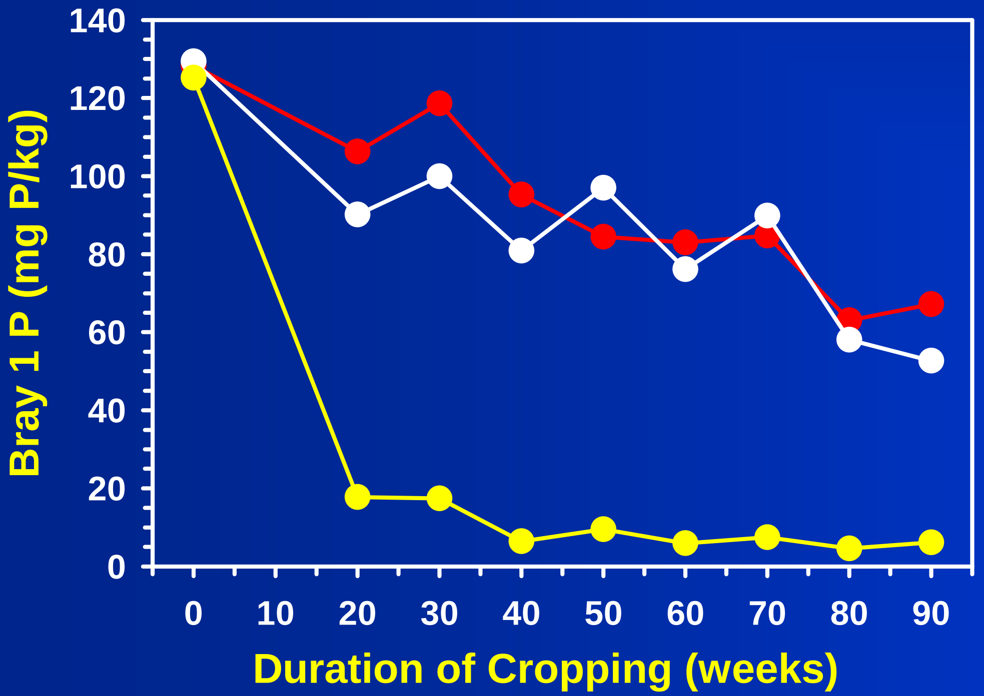
Class A = 43%

Class B = 30%

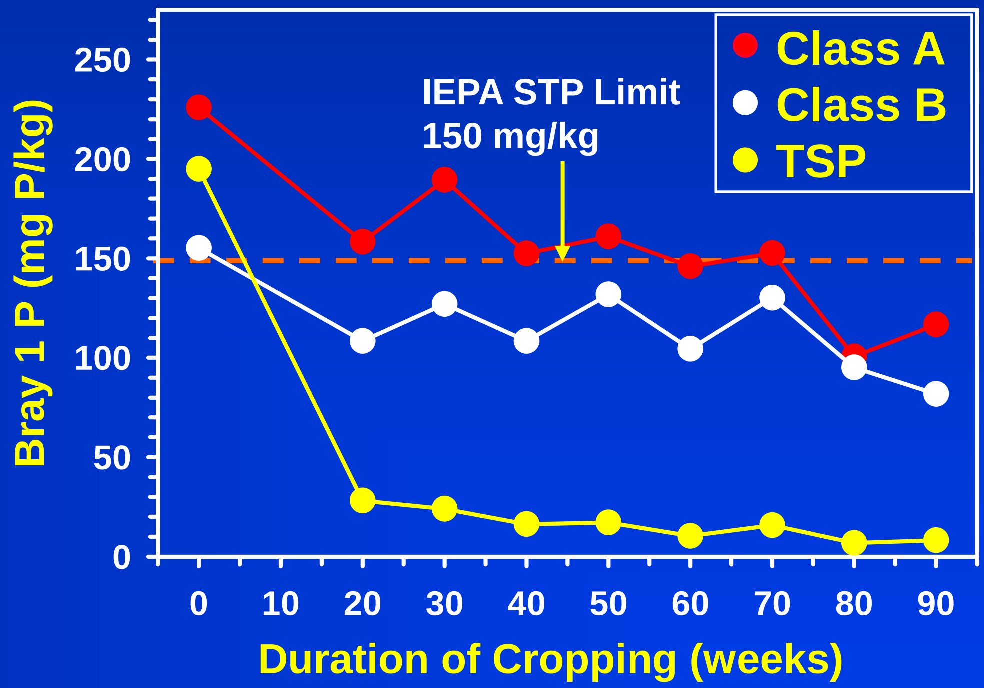
Draw Down of Soil Test P

How long does it take to get back?

P Added = 200 mg P/kg (400 lbs/ac)

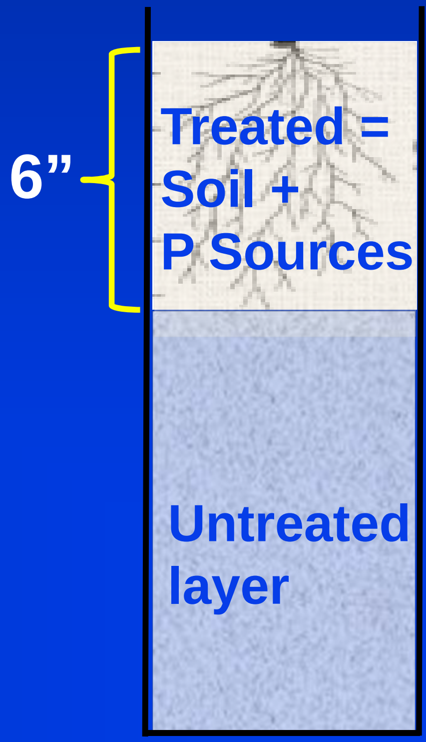


P Added = 300 mg P/kg (600 lbs/ac)



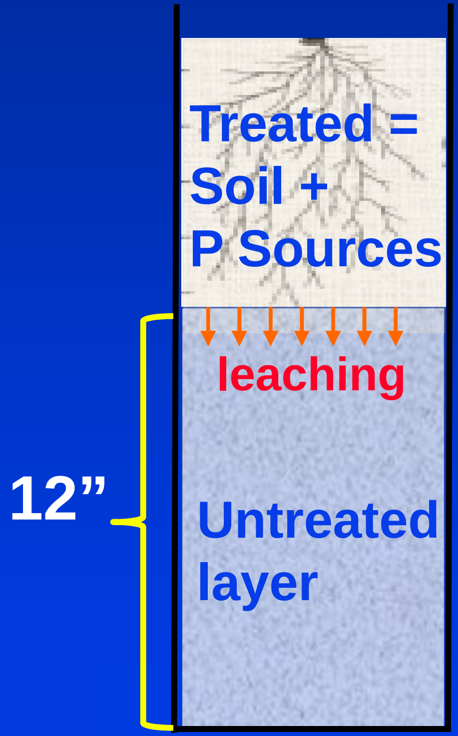
Bray 1 Soil Test P in Top Layer of Pots After 18 Cycles of Cropping

P Rate	Class A	Class B	TSP
mg P/kg	---------------	mg P/kg	---------------
0	0.7	0.7	0.7
25	3.1	3.5	1.7
50	5.5	6.8	1.5
100	20.1	14.9	2.1
150	45.1	34.3	3.6
200	67.1	52.7	6.1
300	116.6	81.8	8.2

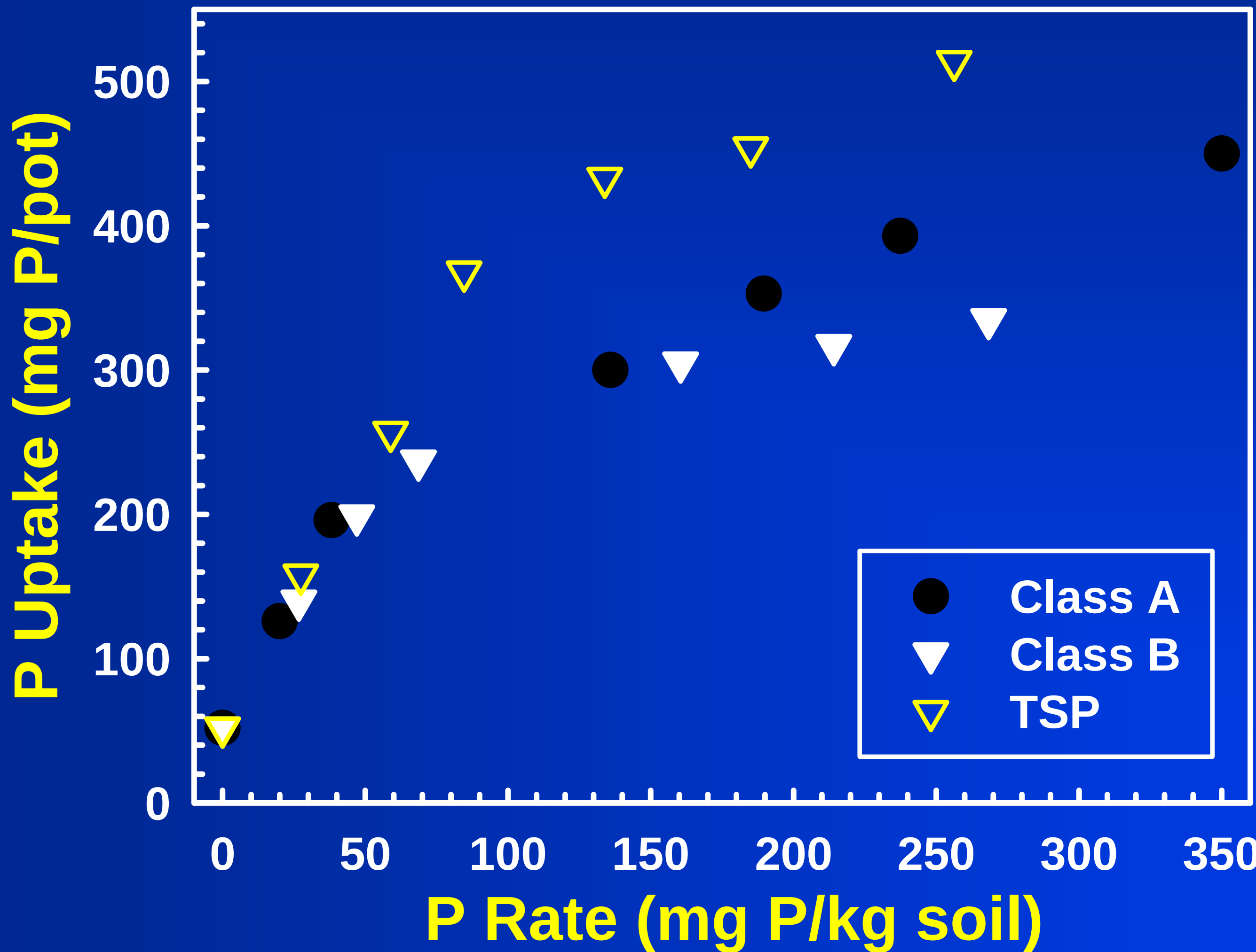


Water Soluble P in Bottom Layer of Pots After 18 Cycles of Cropping

P Rate	Class A	Class B	TSP
mg P/kg	--------------	mg P/kg	--------------
0	0.6	0.6	0.6
25	1.28	1.65	1.72
50	2.36	2.33	2.71
100	3.21	3.45	5.21
150	5.64	5.13	10.23
200	7.38	6.49	15.78
300	7.35	6.42	26.38

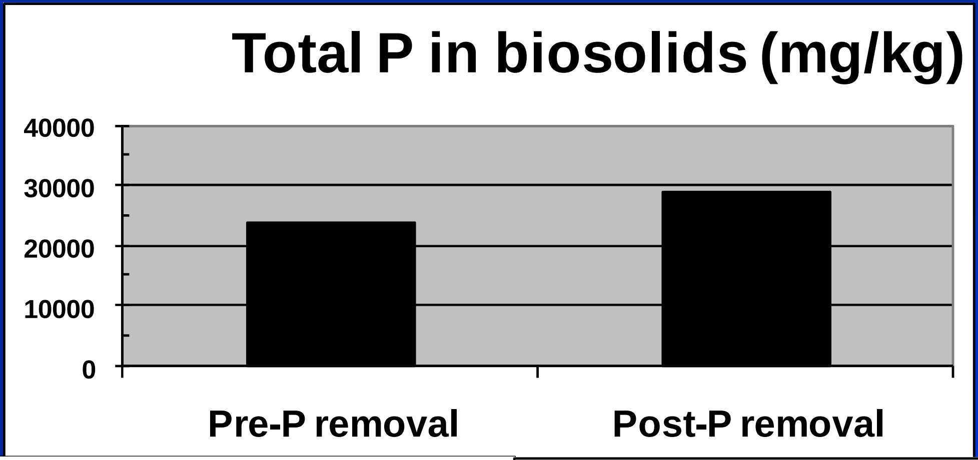


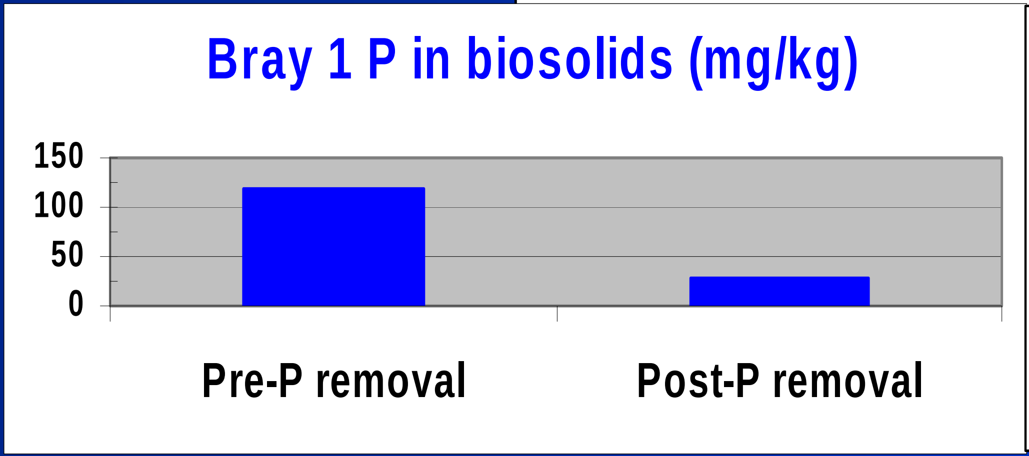
Cumulative P Uptake in 18 Consecutive Foliage Clipping: Long-term Plant Availability

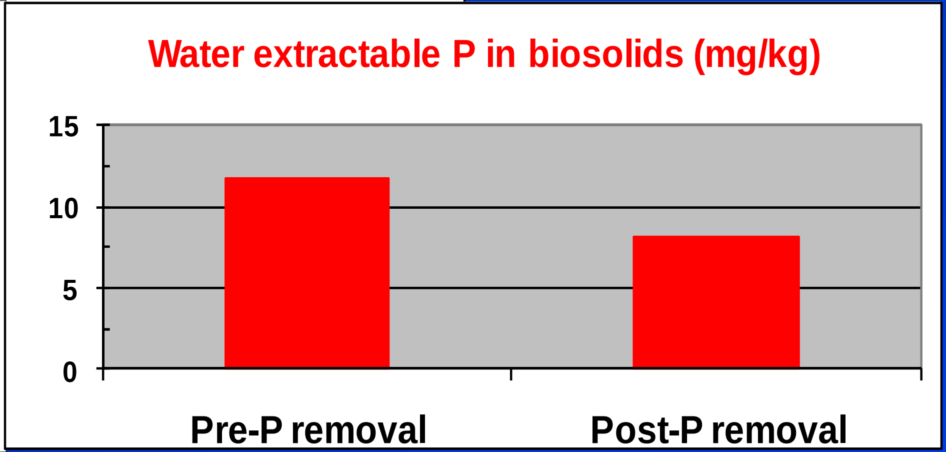


How Might P Removal Affect Biosolids P?

Effect of Chemical P Removal on P in Biosolids from Pilot Study at Egan WRP







Bioavailability: Greenhouse Summary

1. **Bioavailability: Short-term (i.e. first season)**
   - Bioavailability of biosolids P is less than 50% compared to TSP fertilizer
   - Biosolids less effective than TSP to increase STP
   - To raise STP by 1 lb biosolids P required is ~8 lbs in clay loam soils and ~4 lbs in sandy soils
2. **Bioavailability: Long-term**
   - Bioavailability of biosolids P is similar to TSP due to slow availability of residual in soil
   - Draw down of STP over time is slower for biosolids P than for TSP

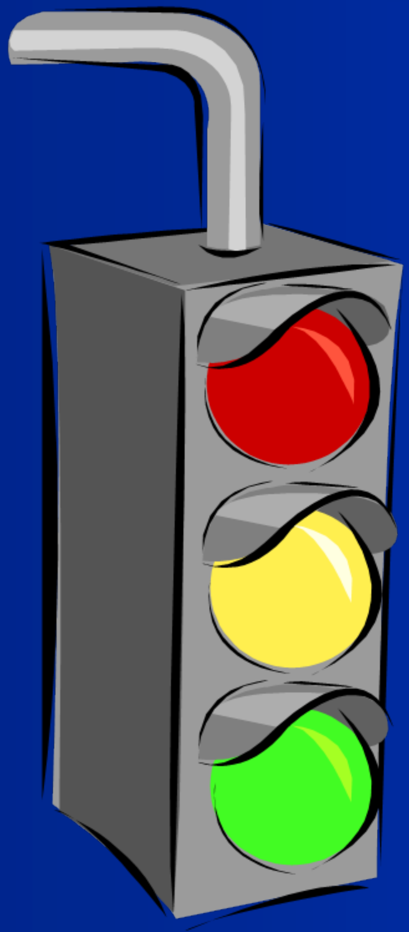
Over To Tian

Confined Animal Feeding Operations

"Meat Factories"

USDA-NRCS 590 Standard

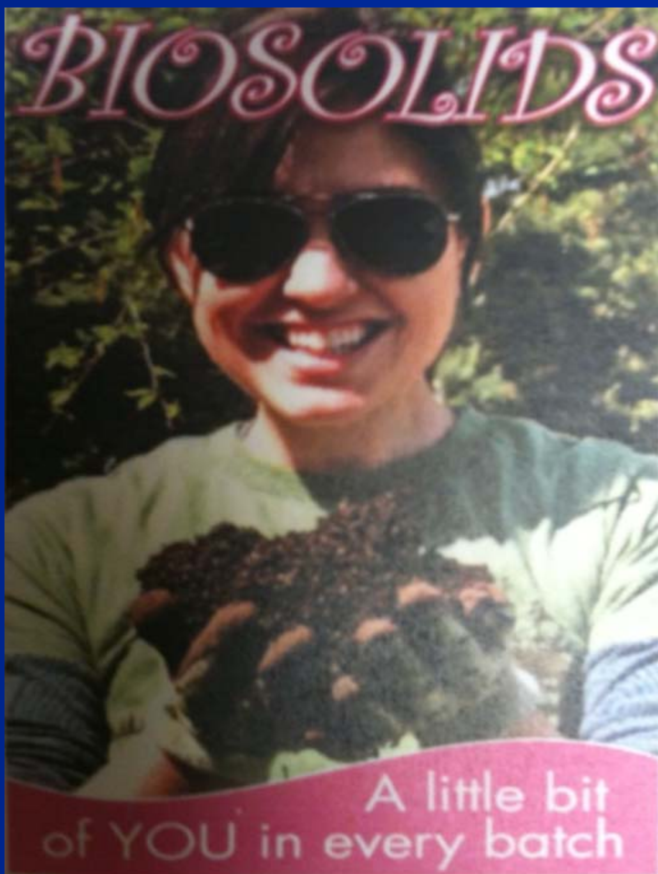
Navigating the Phosphorus Traffic



Field P Rating	Determination of P Application Rate	Biosolids Land Application
HIGH	Prohibited	Prohibited
MEDIUM	P-Based	NOT Practical
LOW	N-Based	Feasible

So What's Your Contribution?

What we eat, drink, and use



High P Diet

Low P Diet

Vegetarian/Vegan

Tax break?

I am what I ate, and I scared – Bill Cosby

Fulton County Field Study

Experimental design

Design: Randomized complete block

Replication: Four

Treatments (P levels in kg P ha^{-1}):

Control (no P)

163:	**Biosolids-P vs. P fertilizer**
325:	**Biosolids-P vs. P fertilizer**
488:	**Biosolids-P vs. P fertilizer**
650:	**Biosolids-P vs. P fertilizer**

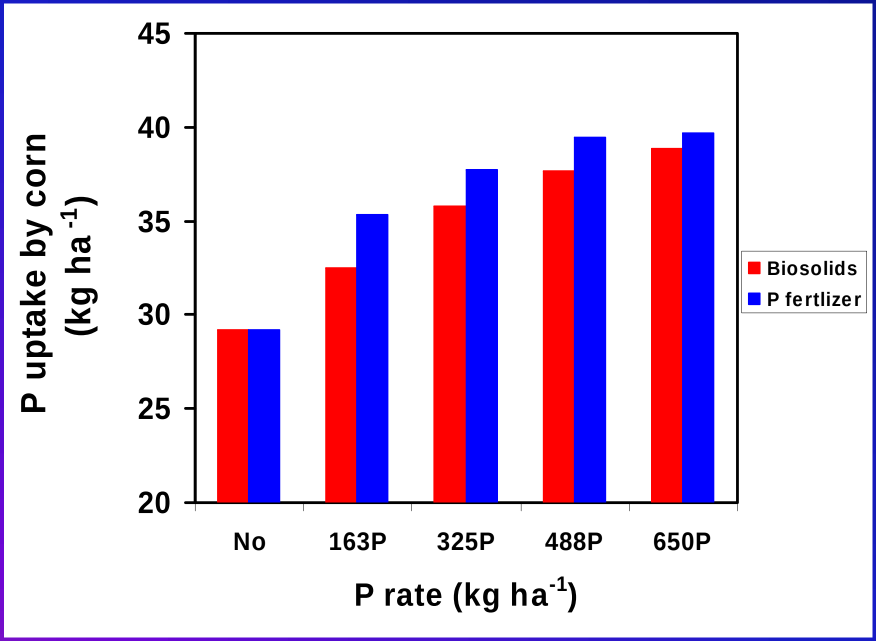
Fulton Country, W. Illinois

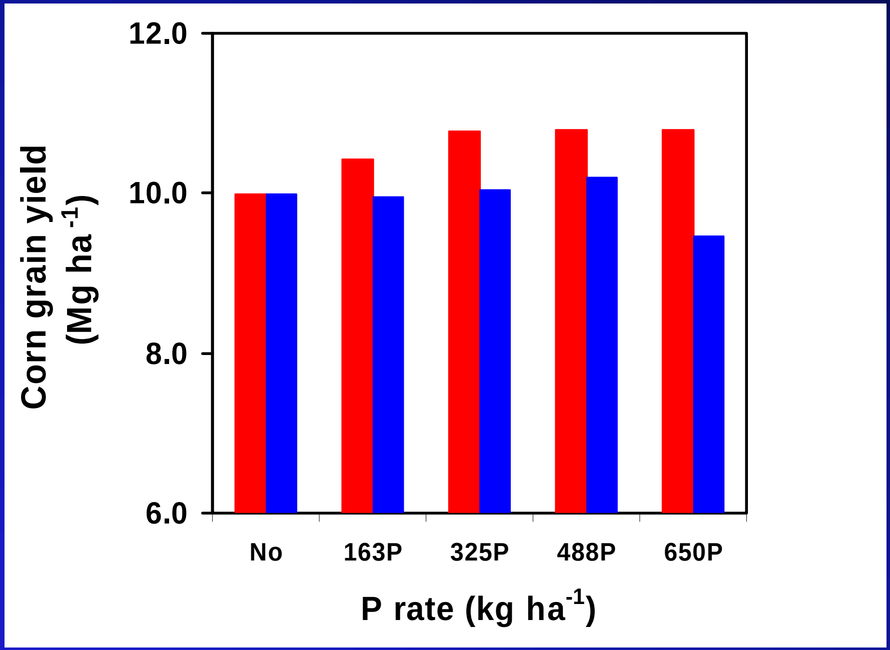
- One application (10/2005): biosolids and Triple SuperPhosphate (TSP, P fertilizer)

- Initial soil Bray-1 P: 13 ppm

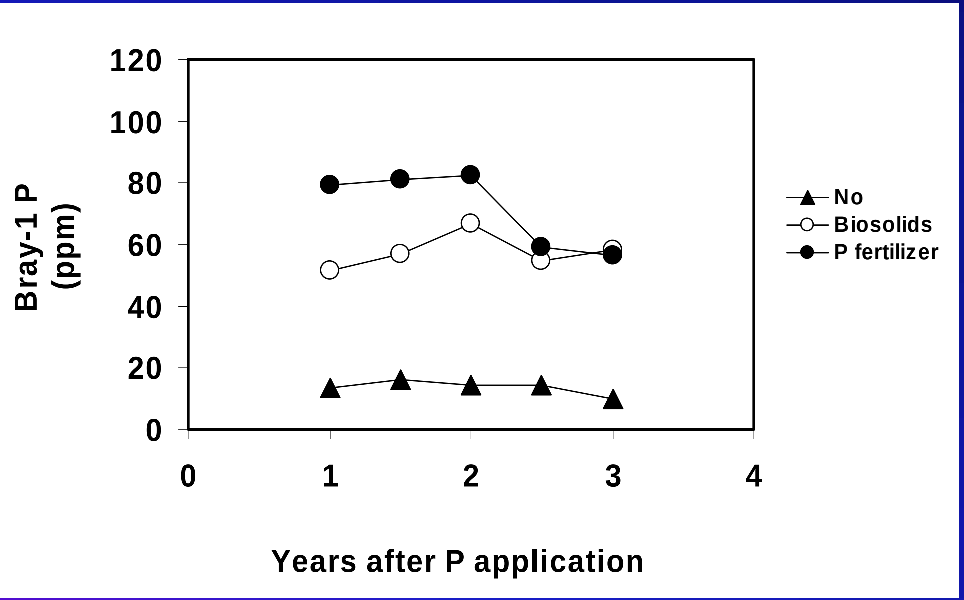
- pH 5.8
- O.C.: 2%
- Soil texture: Silty clay loam

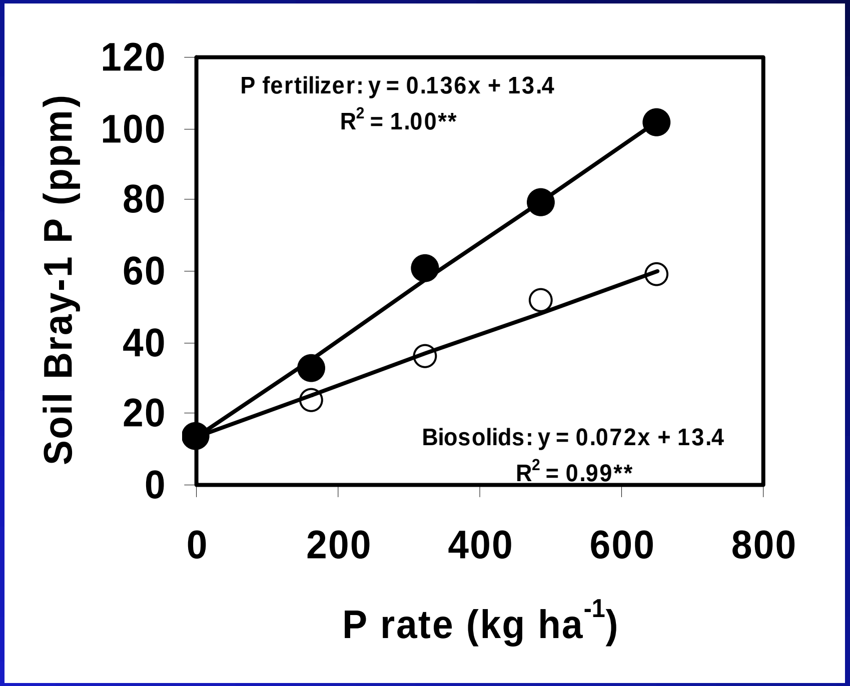
Agronomic effectiveness





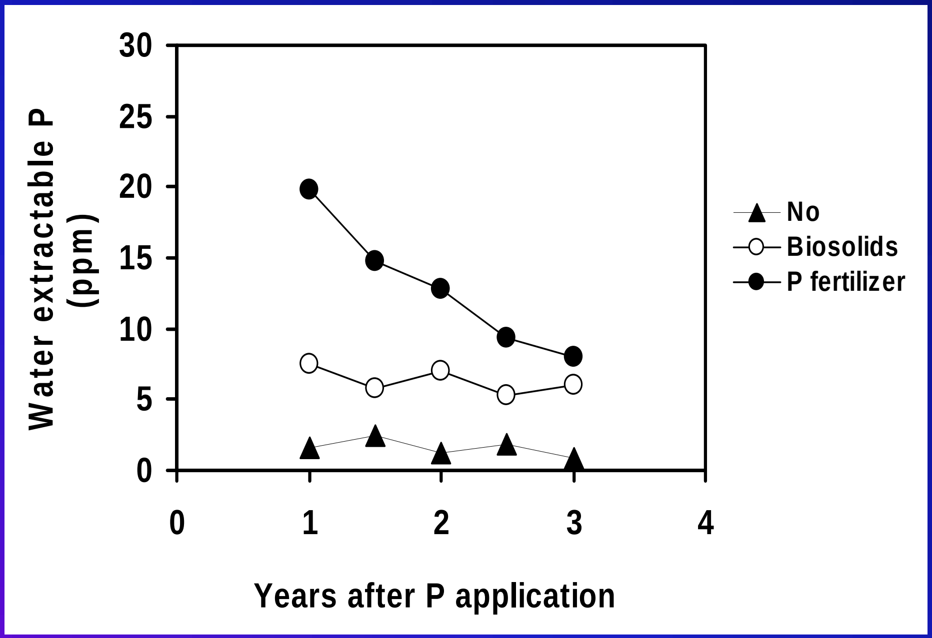
Dynamics of soil Bray-1 P and effectiveness of biosolids in raising it

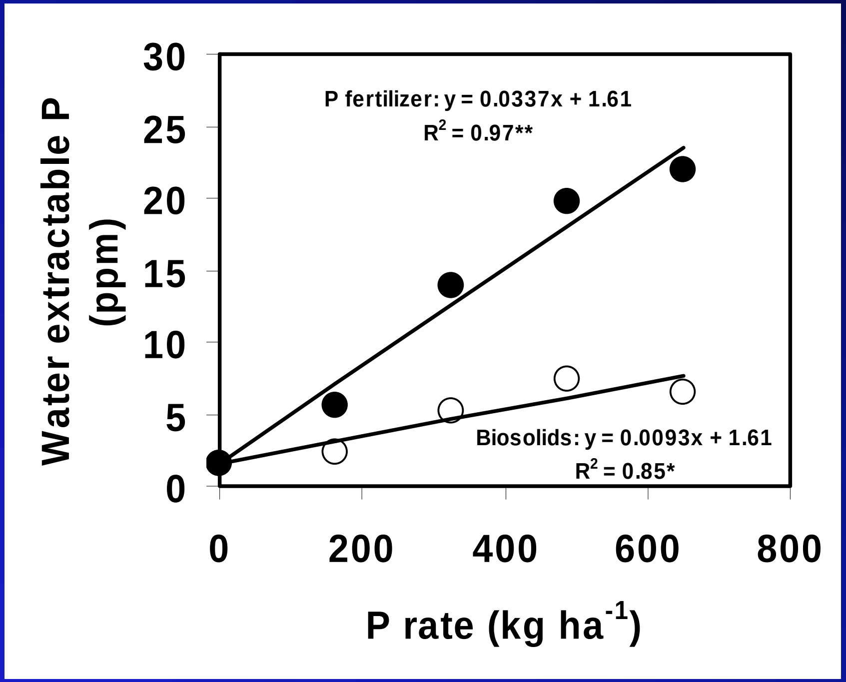




Biosolids ≈ ½ TSP

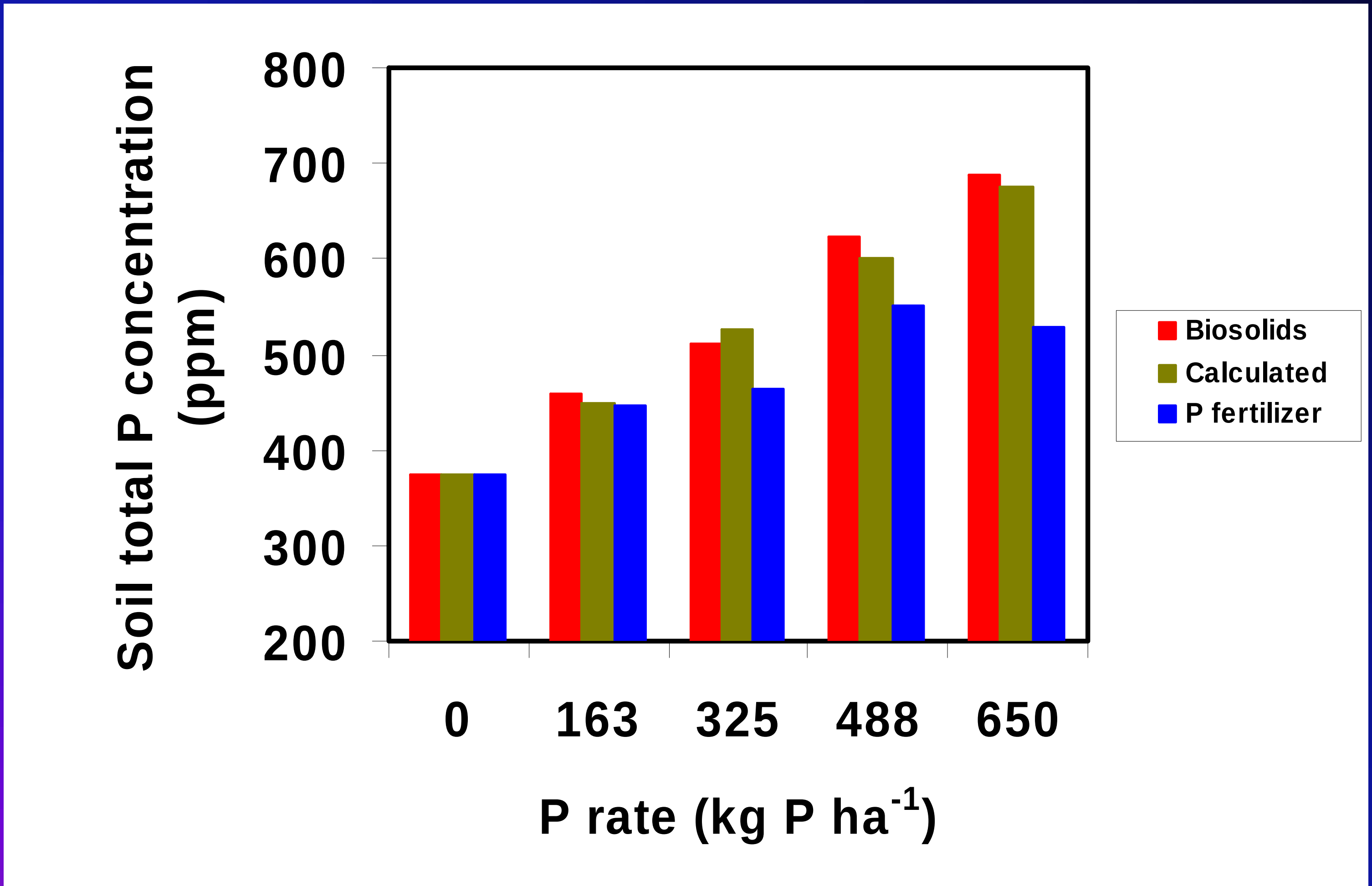
Dynamics of soil water extractable P and the effectiveness of biosolids in raising it



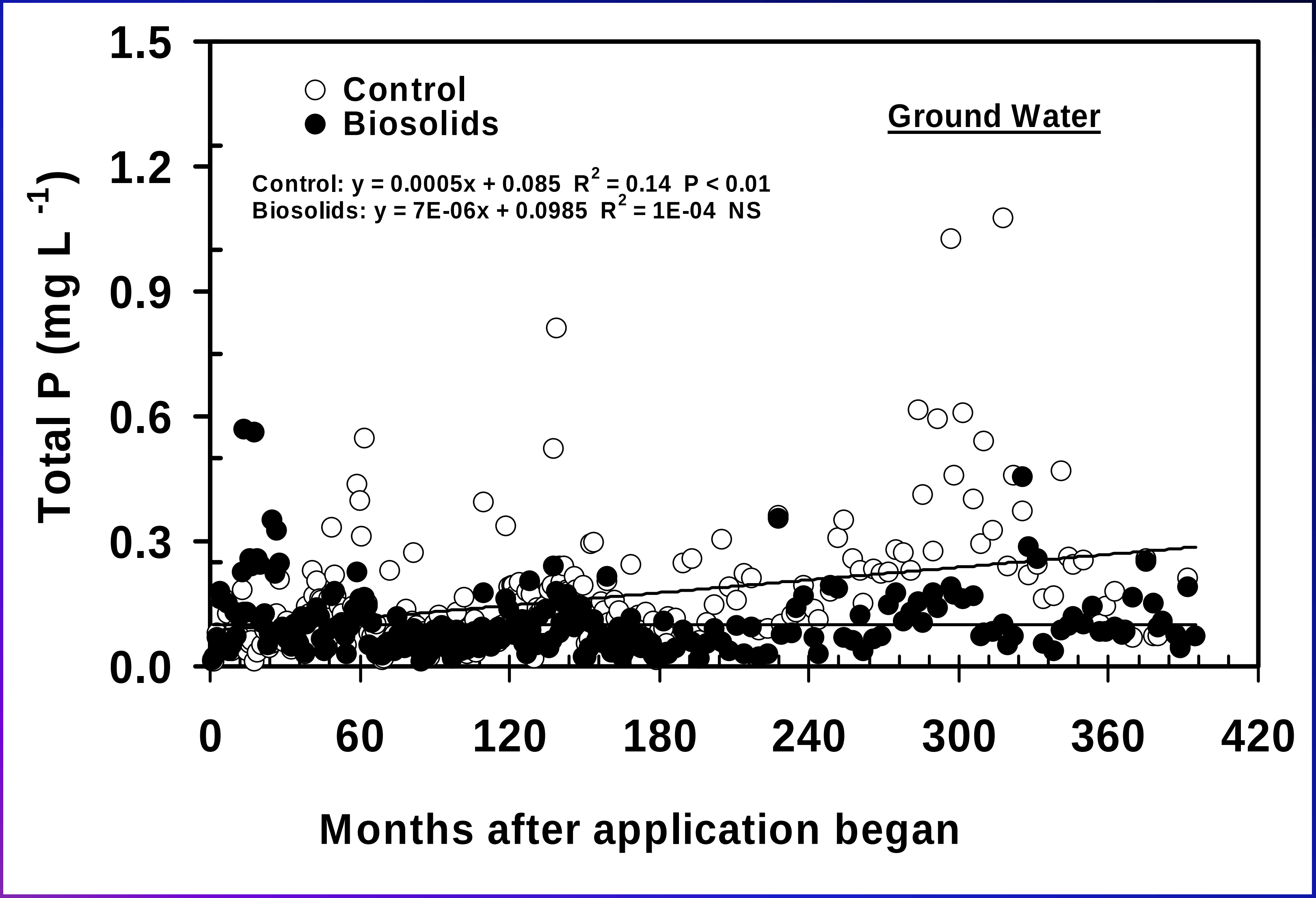


Biosolids = ¼ - ⅓ TSP

Recovery of P at 3 years after the P application



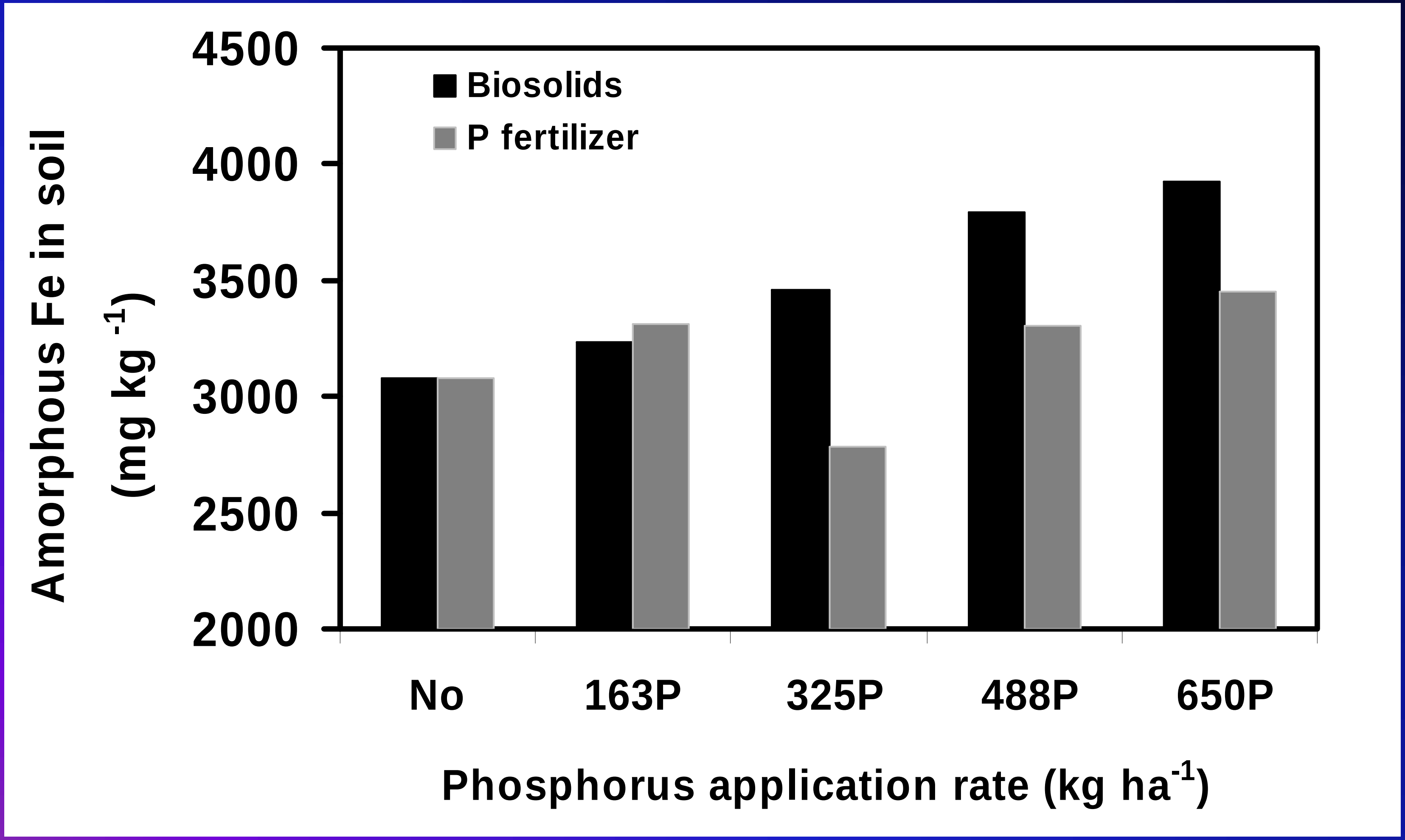
Long-term data support less leaching of P from biosolids



Biosolids Fe/Al add to soil P fixation capacity

- $Fe(OH)_n^+$
- $H_2PO_4^-$
- Fe-P complexes
  Adsorption and co-precipitation

Amorphous Fe oxides increase along the biosolids application



Residual effects:
Cropping years to return to initial P level

Soil Bray-1 P

(agronomic effectiveness)

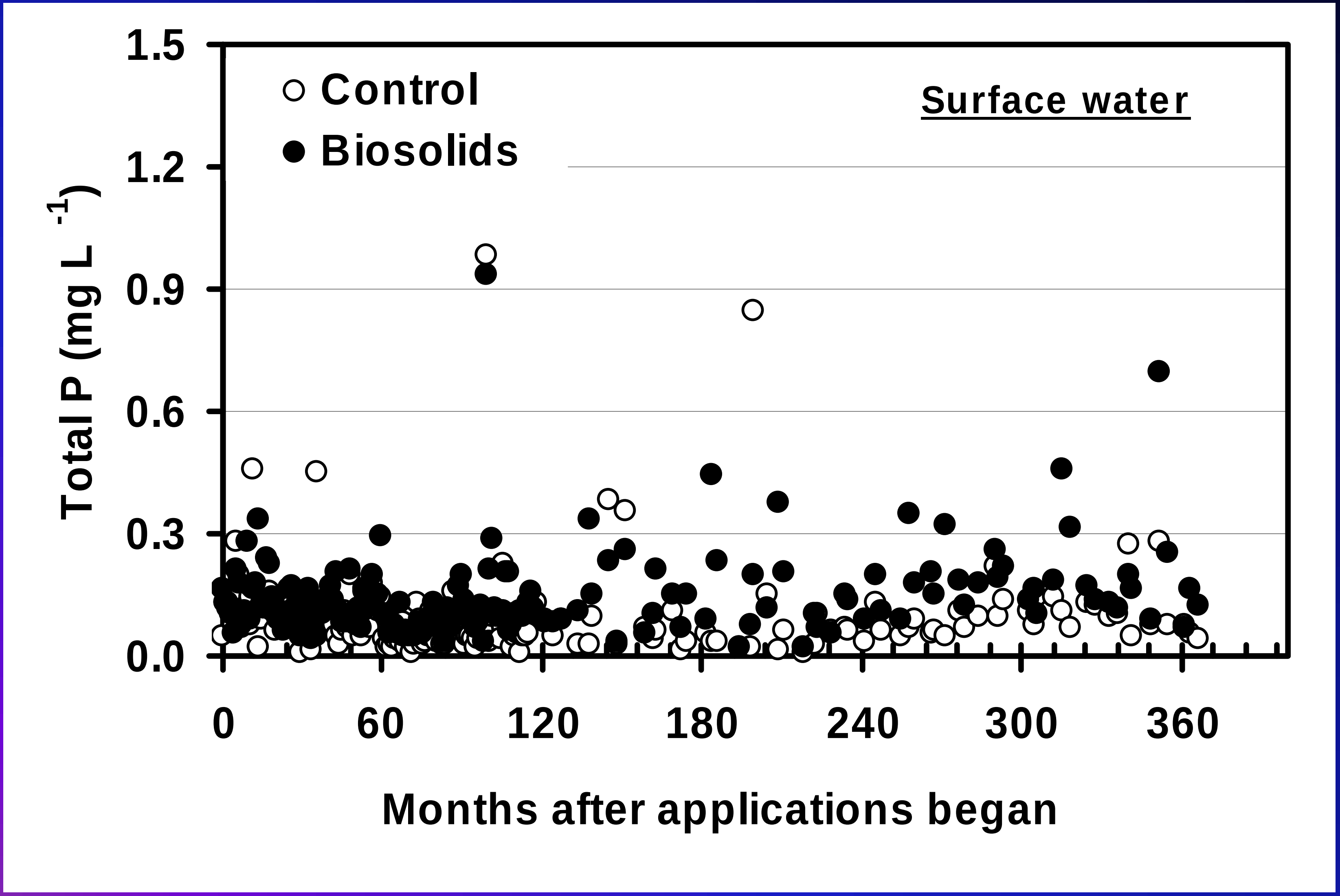
P fertilizer	**<4 yr**
Biosolids	**> 4 yr**

Water extractable P

(environmental risk)

P fertilizer	**<3 yr**
Biosolids	**> 3 yr**

Surface water at Fulton County long-term biosolids application watershed



Conclusions

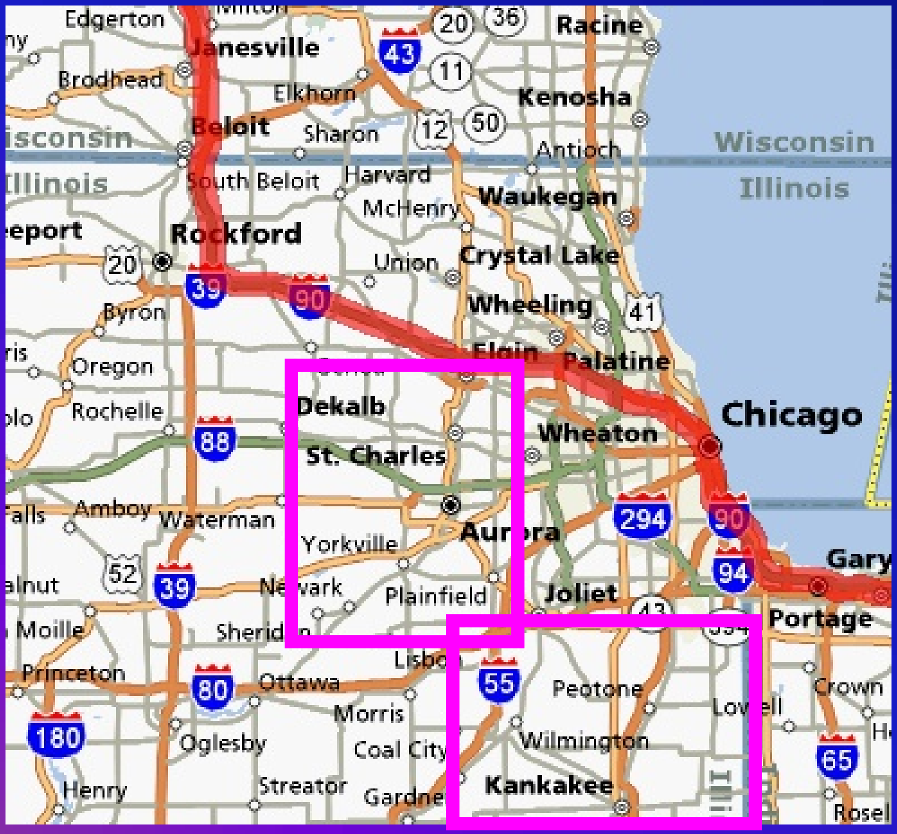
- **Possible:**
  N-based biosolids land application

- **Not possible:**
  yearly repeated application

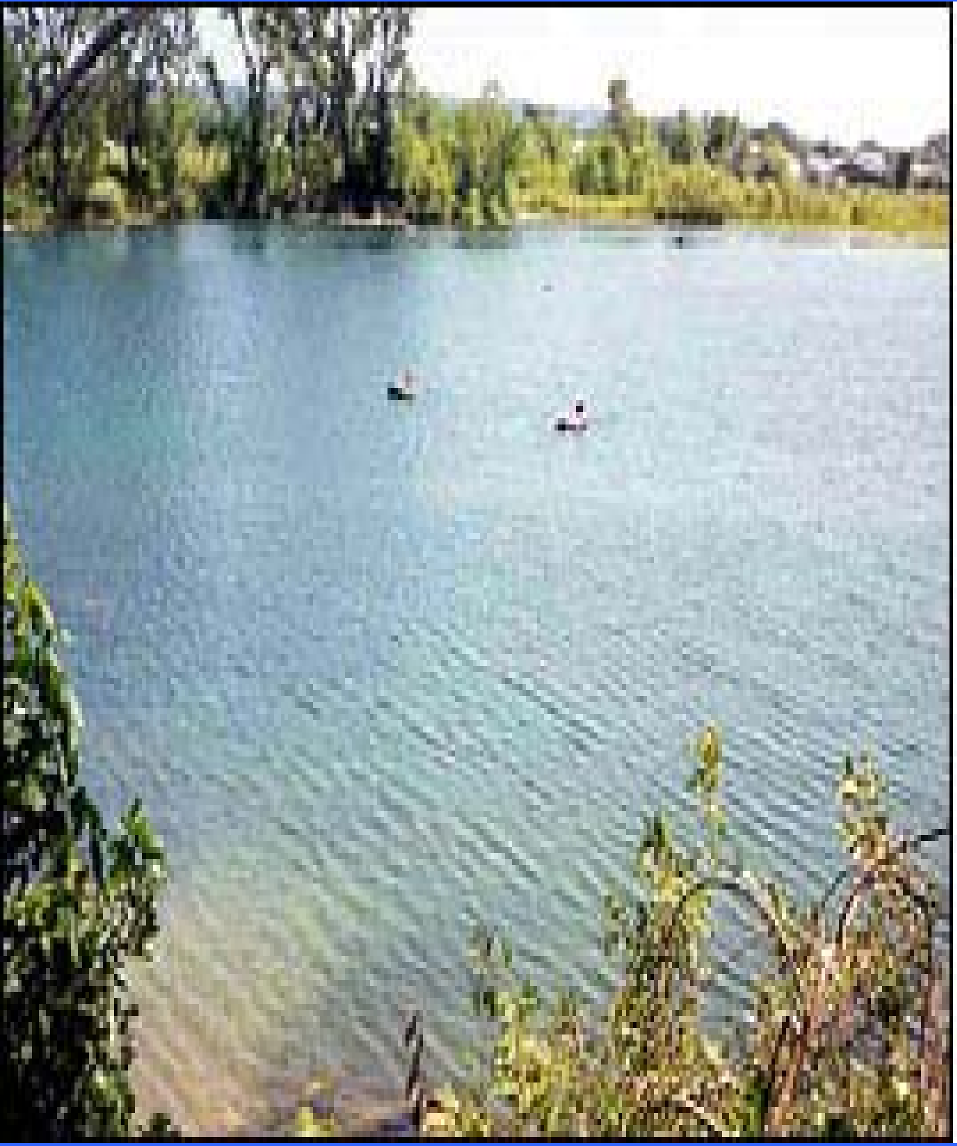
Recommendations for biosolids land application program

A Nitrogen-Based 5-Year Rotation

Potentials of farmland in Chicagoland for biosolids use



- South block: 30 X 40 mile
- West block: 30 x 40 mile
- Crop land: 400k ha
- MWRD biosolids farmland: 100k Mg yr^{-1}
- Biosolids 20 Mg ha^{-1}:
- Land needed for biosolids: 1%
- Rotate every 5 yr, only use 5 % land




But Phosphorus is a Good Thing

Humans and Animals

- Essential ingredient of all cell protoplasm, nervous tissue, and bones
- Part of DNA material and energy distribution

Plants

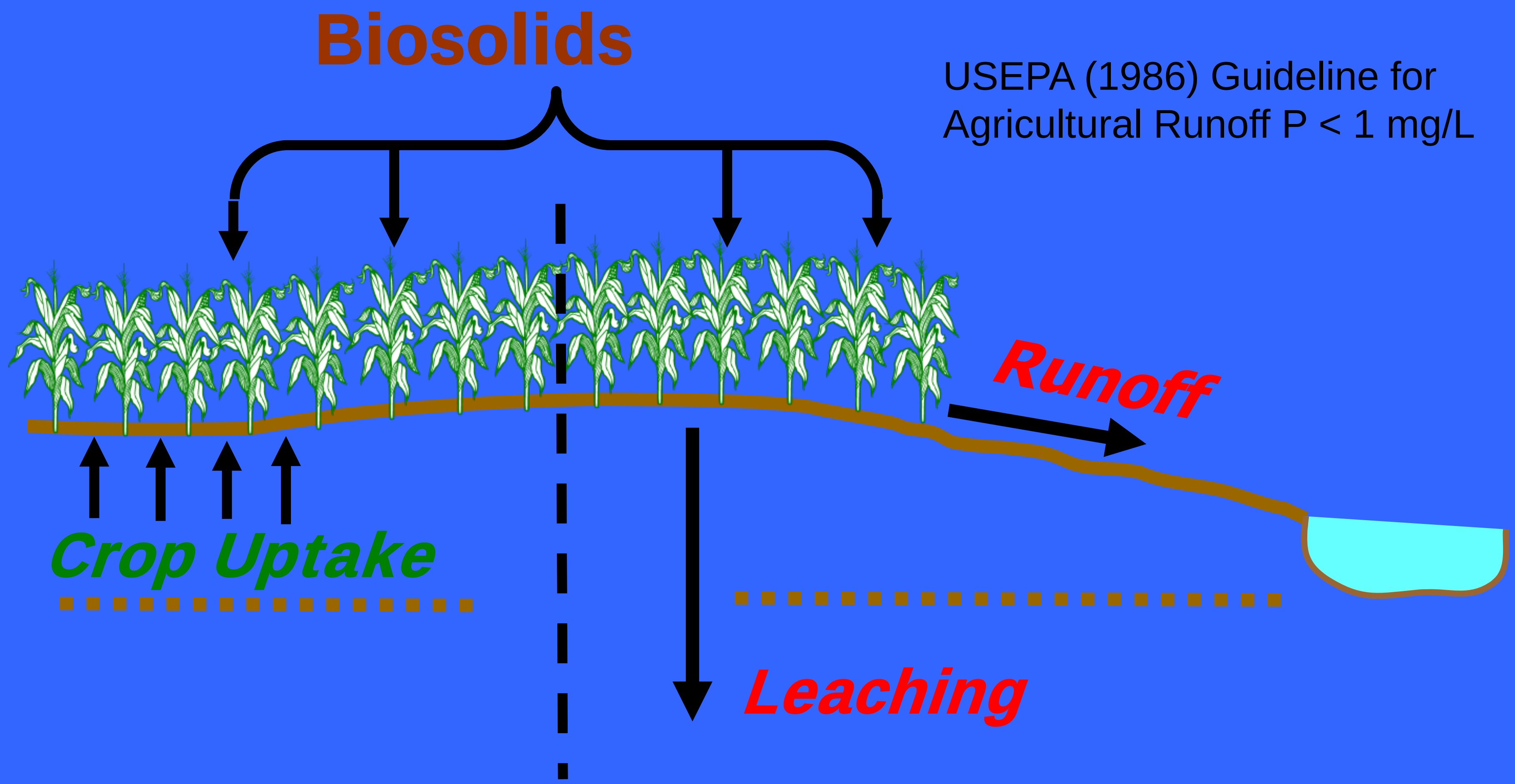
- An essential plant macro-nutrient
- Formation of sugars and starches and conversion of solar energy into chemical energy
- Stimulation of early growth and root formation, and promotes plant hardiness and seed production

Good for ROOT Growth of both Plants & Human Hair

AGRONOMIC IMPACTS

ENVIRONMENTAL IMPACTS

USEPA (1986) Guideline for
Agricultural Runoff P < 1 mg/L



Rainfall Simulation Study

Objective: To compare potential P losses from Class-A & Class-B biosolids when surface applied or mixed (incorporated) with soil.

- **H → No difference in Class-A and Class-B biosolids.**
- **H → Mixing of biosolids will reduce P losses as compared with surface application.**

Treatments

- Rates of Application
  - To meet crop N requirement (N basis)
  - To meet crop P requirement (P basis)

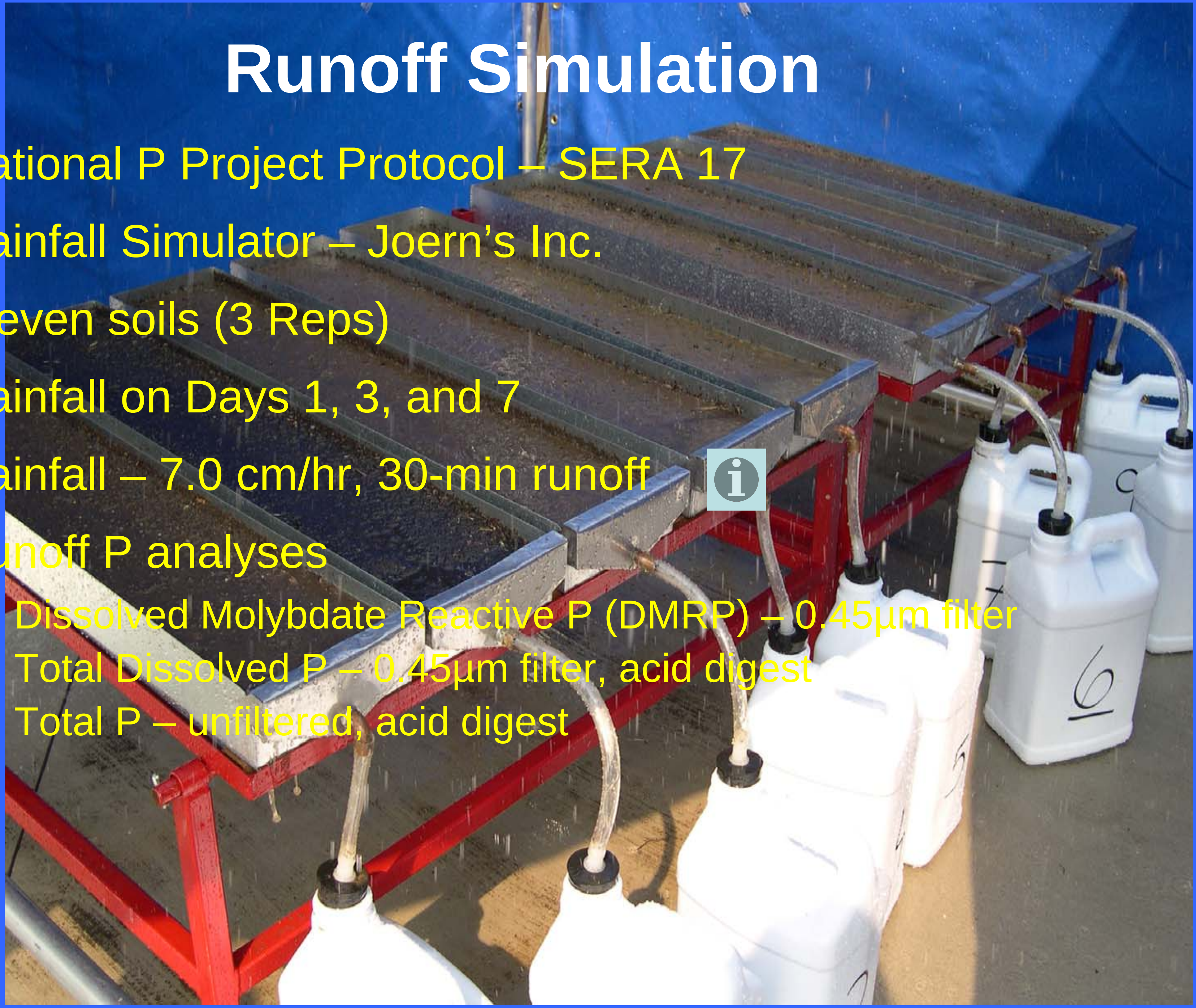
- Method of Application
  - Surface (S)
  - Incorporated (In)

- TSP rates – (Incorporated in soil)
  - Biosolids equivalent P based on N
  - Biosolids equivalent P based on P

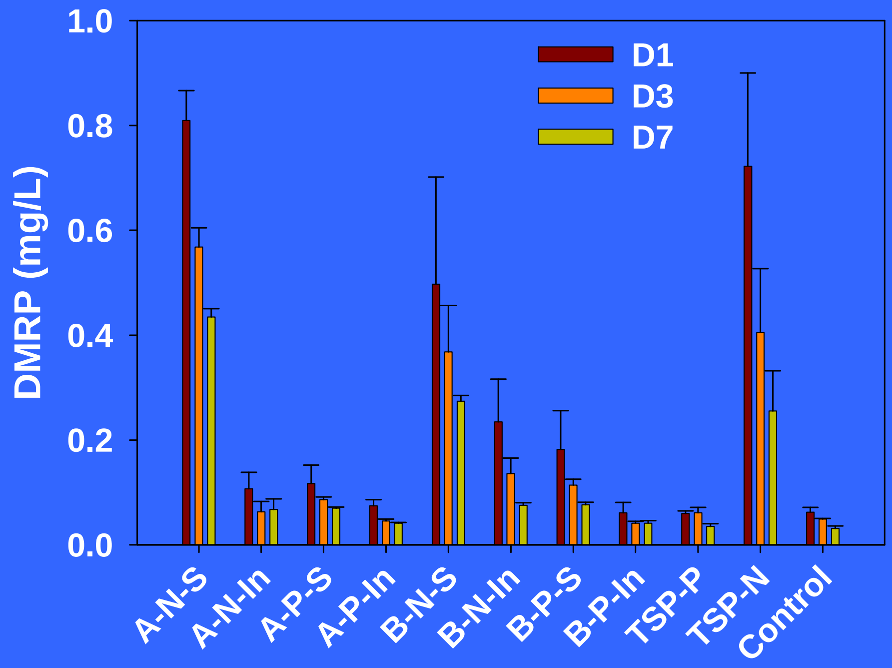
- Control

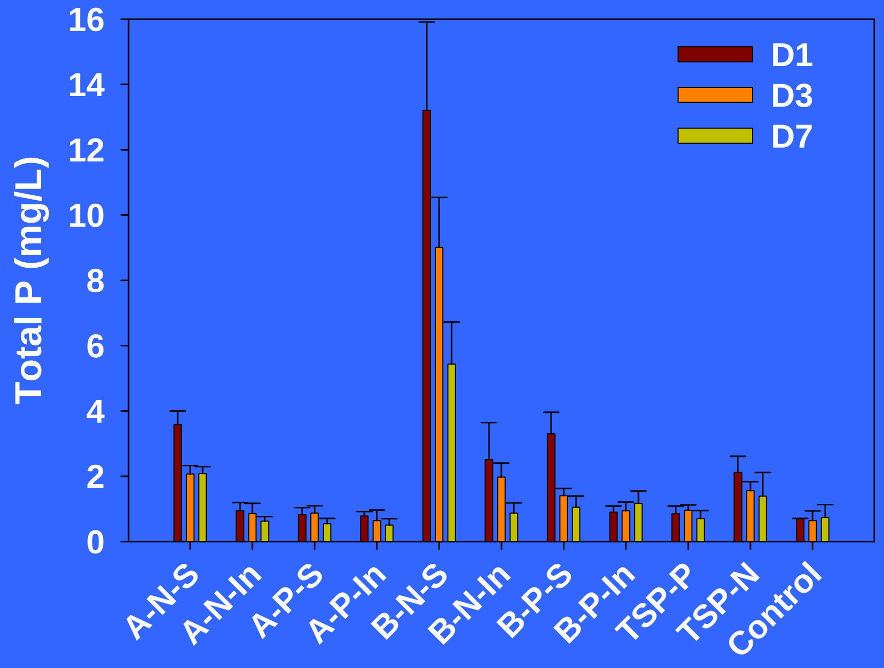
Runoff Simulation

- National P Project Protocol – SERA 17
- Rainfall Simulator – Joern's Inc.
- Eleven soils (3 Reps)
- Rainfall on Days 1, 3, and 7
- Rainfall – 7.0 cm/hr, 30-min runoff
- Runoff P analyses
  - Dissolved Molybdate Reactive P (DMRP) – 0.45µm filter
  - Total Dissolved P – 0.45µm filter, acid digest
  - Total P – unfiltered, acid digest



DMRP and Total P Concentration





DMRP in Runoff

Treatments	P lost during 3 runs (mg/tray)	
	Surface	Incorporated
N-Based		
Class A	9.1	1.3
Class B	5.6	2.3
TSP		7.4
P-Based		
Class A	1.4	0.9
Class B	1.9	0.9
TSP		0.7
Control	0.6	

Particulate P in Runoff

Treatments	P lost during 3 runs (mg/tray)	
	Surface	Incorporated
N-Based		
Class A	27.9	10.1
Class B	128.5	22.5
TSP		18.0
P-Based		
Class A	7.9	8.5
Class B	23.4	16.5
TSP		9.1
Control	7.6	

Total P in Runoff

Treatments	P lost during 3 runs (mg/tray)	
	Surface	Incorporated
N-Based		
Class A	39.5	13.2
Class B	137.2	27.4
TSP		28.0
P-Based		
Class A	11.2	11.1
Class B	29.7	18.7
TSP		10.6
Control	8.7	

Cake and Air-dried biosolids are different

10 mins **30 mins** **5 hrs** **24 hrs**

Summary

- Greater losses of dissolved P occurred from surface applied Class-A biosolids, however total P losses were higher from class-B biosolids.
- Incorporating biosolids reduced the P losses substantially. Biosolids incorporation within 24 hrs of spreading is the best management practice followed in District’s farmland application program.
- Most of the losses were due to particulate P, so controlling erosion may reduce P losses substantially.

Field P Runoff Study

Objective: To compare the length of vegetative buffer strip for reducing particulate P losses from biosolids applied fields.

- **H : Longer the buffer strip, less will be particulate P losses.**

Treatments

P Sources = 2

Biosolids-Cake: (10dt/ac) = 210 lbs P/ac

TSP: Crop requirement

Vegetative Buffer = 3

0 ft

25 ft

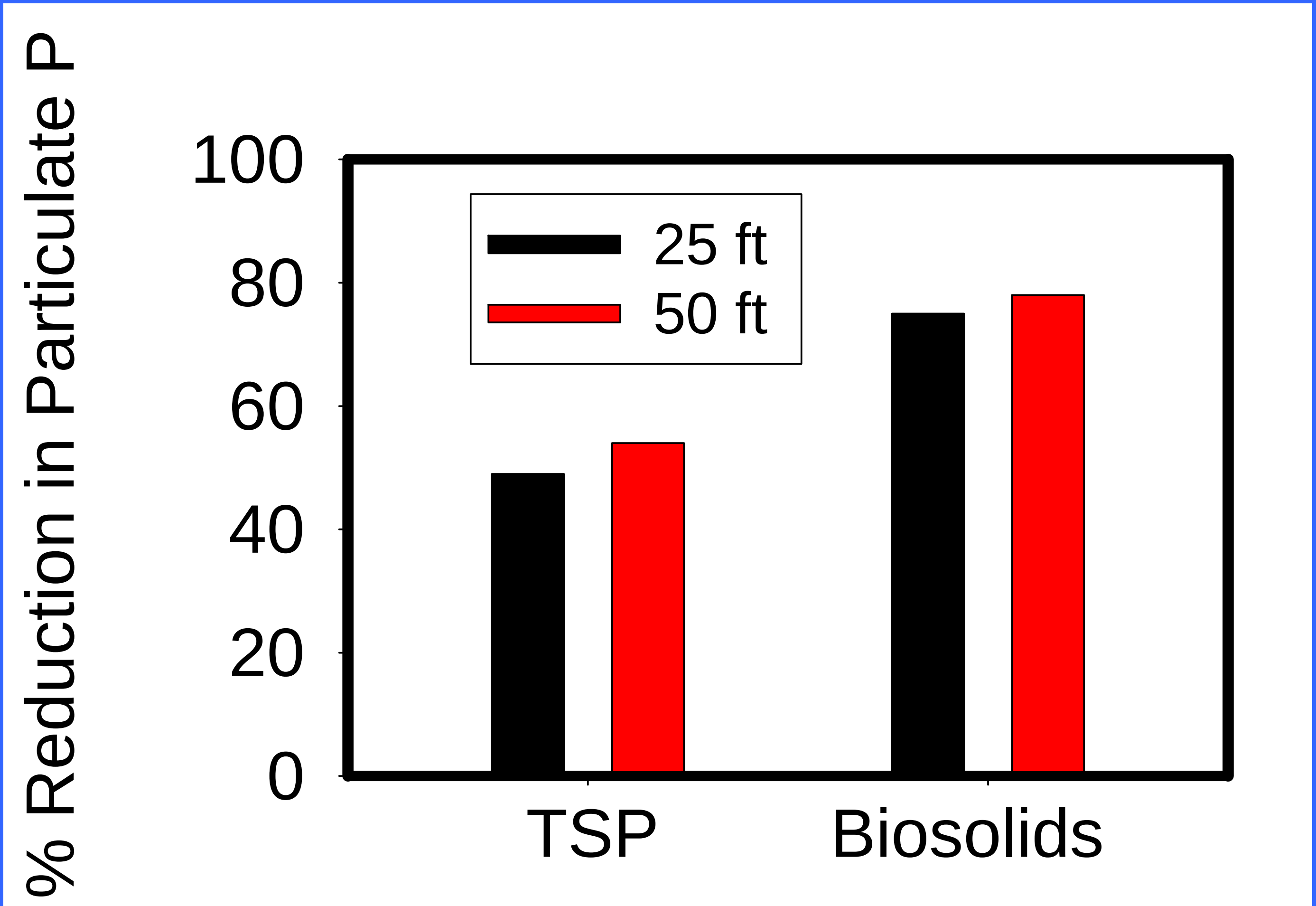
50 ft

Replications = 3

All the Fun at Fulton County: Thanks Rosalie and FC staff

Bring Albert for some hard work next time

Buffer Length and Particulate P

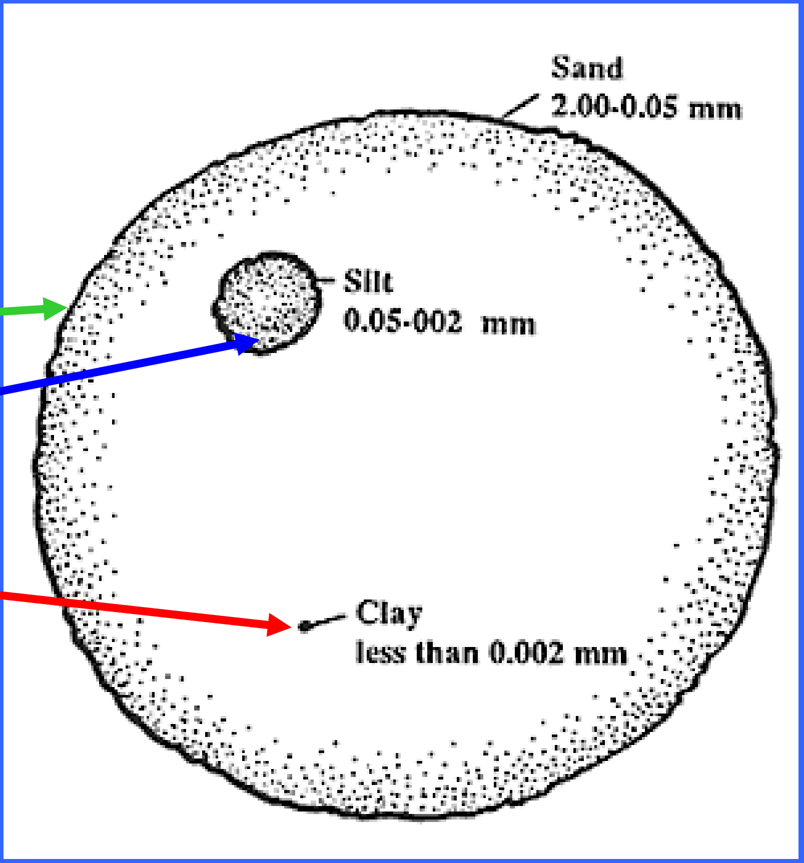


Summary

- We cannot reduce the P in agricultural runoff to ZERO, no matter what is the length of vegetative buffer strip.
- 25 ft buffer length was sufficient to reduce particulate P concentration to < 1 mg/L in 9 out of 10 runoff generating storm events.
- 50 ft is a good conservative length, the suggested length by IEPA for proposed regulation is 100 ft.

Fine-earth fraction
The Three Soil Separates

- Sand - 2.0 - 0.05 mm
- Silt – 50 – 2 um
- Clay - < 2 um



Time to Settle in Water Column
Sand = Secs
Silt = mins
Clay and Colloidal material = hrs

Cake and Air-dried biosolids behave differently

10 mins **30 mins** **5 hrs** **24 hrs**

Imminent P-based Biosolids Land Application Rule

Is the District’s Farmland Application Program at Risk? No

- Selection of fields based on soil test and erosion potential
- Most of the losses were due to particulate P, so controlling erosion may reduce P losses substantially.
- BMP’s (e.g. vegetative buffers, WT-Residual Strips) in sensitive areas

Questions?

All biosolids are created equal but some are more Equal than others

District Biosolids

are

‘Celebrity Biosolids’